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Evolution Of Upper Cretaceous Volcanic And Plutonic Centers And Associated Porphyry Copper Occurrences Tahtsa Lake Area, British Columbia

Donald George Macintyre

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LA THÈSE A ÉTÉ MICROFILMÉE TELLE QUE NOUS L'AVONS REÇUE

EVOLUTION OF UPPER CRETACEOUS VOLCANIC AND PLUTONIC CENTERS AND ASSOCIATED PORPHYRY COPPER OCCURRENCES

TAHTSA LAKE AREA, BRITISH COLUMBIA

by

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Department of Geology

Submitted in partial fullfillment
of the
requirements for the degree
of

Doctor of Philosophy

Faculty of Graduate Studies
The University of Western Ontario
London, Ontario
June 1976

FRONTISPIECE

View of the south slope of Swing Peak ridge showing exposures of relatively flat lying strata of the Swing Peak Formation. Note columnar-jointed flows capping the western half of the ridge.

Abstract

The Tahtsa Lake area, West Central British Columbia, was mapped at a scale of one centimeter equals 500 meters. In this area, volcanic and sedimentary rocks of Jurassic and Lower Cretaceous age are unconformably overlain by relatively flat-lying volcanic rocks of Upper Cretaceous age. These rocks have been given the name Kasalka Group and represent the remains of a once extensive volcanic cover now largely removed by erosion in most parts of West Central British Columbia. Up to 1500 meters of these rocks are exposed in downthrown fault blocks in the core of Kasalka Range, which is interpreted to be a major cauldron subsidence complex. Evolution of this complex began in earliest Upper Cretaceous with explosive volcanism and deposition of rhyolitic pyroclastic and flow rocks on a relatively level plateau surface. Stratovolcanoes of latite-andesite and lahar formed above this volcanic plateau, peripheral to the area of subsidence. Dykes and stocks of quartz diorite and diorite of Kasalka Intrusions crystallized slowly beneath these volcanoes. Extensional rifting occurred during the final stages of each volcanic event, accompanied by injection of porphyritic rhyolite and porphyritic granodiorite phases of Bulkley Intrusions. Hydrothermal activity and mineral concentration of the porphyry copper type occurred at this time. Rifting continued into Tertiary time with formation of northwest-trending dyke swamms and localization of the Coast and

Nanika Intrusions. The sequence of events in evolution of Tahtsa Lake area parallel those of the modern Andes of South America and are consistent with plate tectonic models for evolution of the Canadian Cordillera as a whole.

Acknowledgements

I would like to gratefully acknowledge the assistance of Asarco Exploration Company of Canada, Limited who generously provided field and financial support for this thesis. Without their help and encouragement this work would not have been possible. I am also indebted to my chief supervisor, Dr. R.W. Hodder of the University of Western Ontario, for providing many helpful suggestions and criticisms during the course of research and writing. In addition, I would like to thank Dr. R.W. Hutchinson for critical reading of the manuscript, Drs. R.C.O. Gill and B.J. Fryer for assistance in the analytical work, John Forth for preparation of thin sections, Ms. B. Olson who typed the first draft, and Mrs. Stella Mitchell who typed the final draft. The author was ably assisted in the field by Messrs. J. Wedley, R. Woods and R. MacGregor. Finally, I would like to thank Jackie and Michael MacIntyre for their encouragement and patience throughout the preparation of this thesis.

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CHAPTER 1

INTRODUCTION

1.1 Statement of Purpose

Porphyry copper occurrences are associated with Upper Cretaceous plutonic rocks in the Tahtsa Lake area of West Central British Columbia. Despite the economic significance of these occurrences, very little information was available on their regional geologic setting. Consequently, it was decided to map the area in detail. During the course of this mapping, it was discovered that part of the Tahtsa Lake area was covered by volcanic rocks of earliest Upper Cretaceous age. Rocks of comparable age and lithology have been removed by erosion in most parts of West Central British Columbia. Consequently, the Tahtsa Lake area provided an excellent opportunity to study these rocks and in particular, their possible relationships to plutonic rocks of similar age. Therefore, the present study was conducted with the following primary objectives:

1. Preparation of detailed geologic and tectonic maps of the Tahtsa Lake area, with particular emphasis on Upper Cretaceous rock units.
2. Development of a petrogenetic model for evolution of Upper Cretaceous volcanic and plutonic centers and associated porphyry copper occurrences.
3. Definition of major tectonic regimes in the Tahtsa Lake area and their significance to evolution of the Pacific Orogen ~~as~~ a whole.

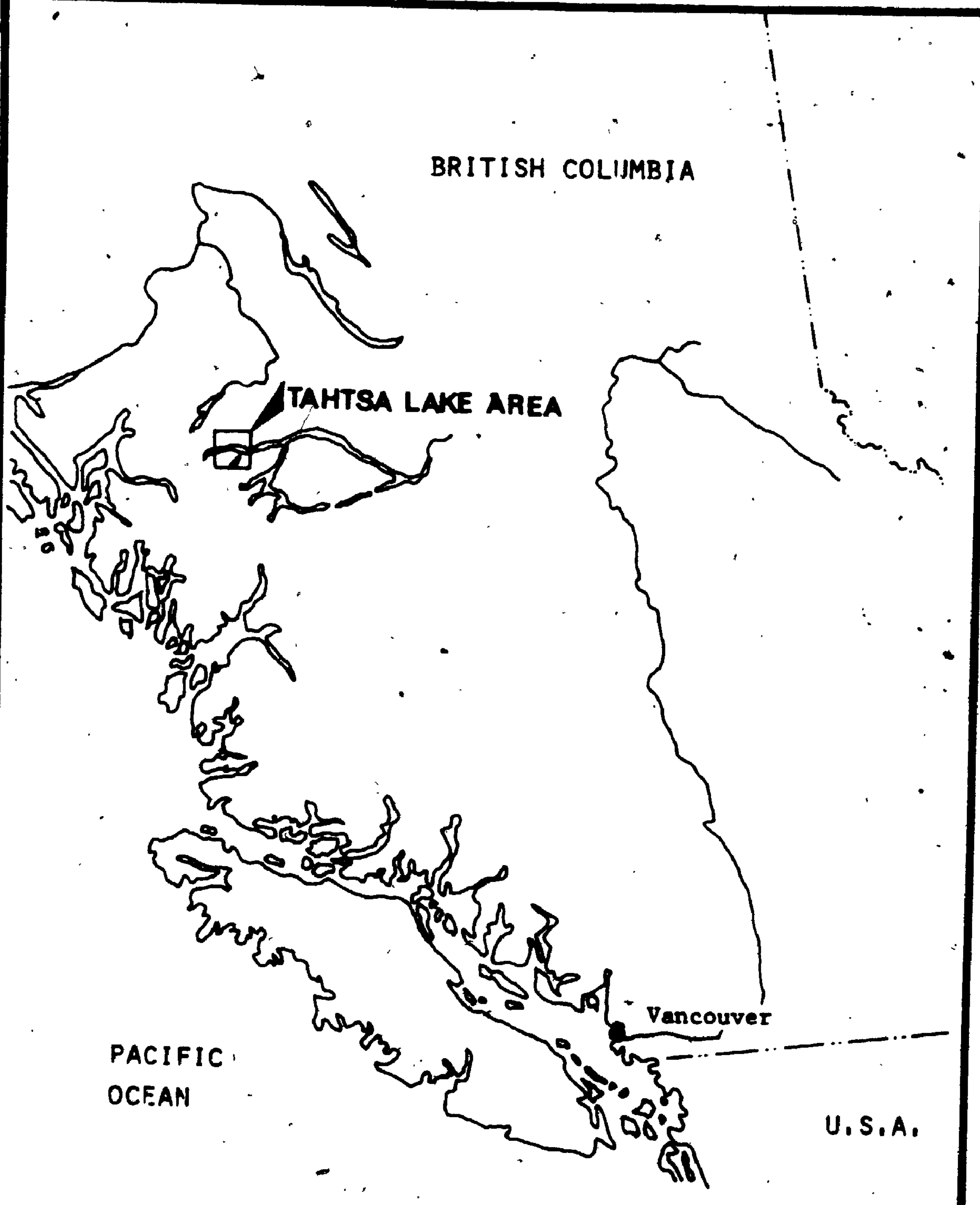


FIGURE 1 LOCATION OF THE TAHTSA LAKE AREA, WEST CENTRAL BRITISH COLUMBIA

1.2 Location and Access

The study area is between latitudes 53°30'N and 53°32'N, and longitudes 127°00'W and 127°30'W (Figure 1). Tahtsa Lake is at the geographic center of this area and is accessible via forestry access road from the town of Houston, a distance of 85 Km. Terrane south of Tahtsa Lake can only be reached by helicopter, or by boat across the lake, thence by foot.

1.3 Physiography, Outcrop Distribution and Glaciation

The Tahtsa Lake area is part of a transitional zone between the Coast Mountains to the west and the Interior Plateau to the east. In this area, ridges and peaks to 2400 meters rise above an average base level of 1000 m. In spite of pronounced relief, outcrops are generally restricted to steeper slopes and peaks, and downcutting stream gullies. U-shaped valleys between ranges are filled with fluvioglacial debris and generally lack outcrop. The best and most easily accessible outcrops are on the shorelines of Tahtsa and Troitsa Lake.

The Tahtsa Lake area was extensively glaciated during the last ice age and alpine glaciers still occupy cirque valleys surrounding the higher peaks. Remnants of a once continuous upland surface are preserved above 1800 meters in the Sibola Range (Church, 1971) suggesting this area may have been part of a plateau prior to glaciation.

1.4 Previous Work

The northern half of the Tahtsa Lake area was first mapped by M.S. Hedly of the Geological Survey of Canada in 1935, at a scale of one inch to four miles. From 1947 to 1952, S. Duffell mapped the remainder of the area as part of the Whitesail Lake (NTS 93E) map sheet. In 1961, the Berg porphyry copper deposit was discovered by Kennco Explorations Inc., generating considerable interest in the economic potential of the area. In the following years, six more porphyry copper occurrences were discovered. Geologic information on these occurrences has been published by the British Columbia Department of Mines (Sutherland Brown, 1966, 1969; Church, 1971; Carter, 1970, 1974). Recently, several theses (Cawthorn, 1973; MacIntyre, 1974; Richards, 1974; and Panteleyev, 1976) have been completed on individual occurrences.

1.5 Work Performed

The Tahtsa Lake area, covering an area of approximately 1000 square kilometers, was mapped at a scale of one centimeter equals 500 meters in the summers of 1973 and 1974. A total of 525 rock samples were collected from this area, and from these, 186 thin sections were prepared and studied in detail. In addition, the whole rock chemical composition of 42 samples of Upper Cretaceous volcanic and plutonic rocks were determined by the author using the x-ray fluorescence equipment in the Department of Geology, University of Western Ontario. The K-Ar isotopic ages of three whole rock samples were determined by Teledyne Isotopes Inc.

CHAPTER 2

REGIONAL SETTING OF TAHTSA LAKE AREA

2.1 Major Tectonic Elements

The Tahtsa Lake area is near the center of the Pacific Orogen (Wheeler et al. 1972), just east of the boundary between the Coast Geanticline and the Nechako Trough (Figure 2). The Coast Geanticline, or Coast Plutonic Complex, is essentially an uplifted core of granitic and metamorphic rocks bounded by northwest-trending faults. By contrast, the Nechako Trough is mainly folded eugeosynclinal rocks of early to mid-Mesozoic age. The trough is overlain by successor basin deposits of the Bowser Basin and by Late Mesozoic to Early Cenozoic continental sedimentary and volcanic rocks. The northeast-trending Skeena Arch transects the Nechako ~~Trough~~ and has probably been a tectonic element since Early Mesozoic time.

2.2 Regional Geology

The major geologic formations in West Central British Columbia are summarized in Table 1. The most significant of these in terms of areal extent, is the Jurassic Hazelton Group (Leach, 1910; Hanson, 1935, Armstrong, 1944; Tipper, 1955, 1971) which is basement for most of the Nechako Trough. The Hazelton Group consists mainly of folded andesitic volcanic and sedimentary rocks, typical of volcanic island arc assemblages. Within and south of Bowser Basin, including Tahtsa Lake area, Hazelton

TABLE 1

REGIONAL TABLE OF FORMATIONS,
WEST CENTRAL BRITISH COLUMBIA
(modified from Carter, 1974)

EPOCH	FORMATION	LITHOLOGY
PLEISTOCENE AND RECENT		Plateau basalt
EOCENE AND MIOCENE	ENDAKO GROUP	Basalt, andesite, and breccia, minor rhyolite and dacite
EOCENE	GOOSLY LAKE INTRUSIONS	Gabbro, syenomonzonite
	ALICE ARM INTRUSIONS	Quartz monzonite, granite
	NANIKA INTRUSIONS	Porphyritic quartz monzonite
	BABINE INTRUSIONS	Porphyritic quartz diorite, granodiorite
	COAST PLUTONIC COMPLEX	Quartz diorite, granodiorite, quartz monzonite, granitic gneiss.
UPPER CRETACEOUS AND PALEOCENE	OOTSA LAKE GROUP TIP TOP HILL VOLCANIC ROCKS	Andesite, dacite, rhyolite, basalt and related tuffs and breccias
	SUSTUT GROUP	Sandstone, conglomerate, shale
UPPER CRETACEOUS	BULKLEY INTRUSIONS	Porphyritic granodiorite, quartz monzonite and non-porphyritic equivalents
LOWER CRETACEOUS	SKEENA GROUP	Sandstone, shale
UPPER JURASSIC AND LOWER CRETACEOUS	BOWSER GROUP	Conglomerate, sandstone, shale
	KITSAULT INTRUSIONS	Porphyritic andesite, dacite
UPPER JURASSIC	FRANCOIS LAKE INTRUSIONS	Porphyritic quartz monzonite, granodiorite and quartz diorite
LOWER TO UPPER JURASSIC	HAZELTON GROUP	Andesitic pyroclastic and flow rocks, minor dacite and rhyolite; marine sedimentary rocks
LOWER AND MIDDLE JURASSIC	OMINECA INTRUSIONS	Granodiorite, quartz diorite, syenite, gabbro, monzonite
UPPER TRIASSIC TO LOWER JURASSIC	TOPLEY INTRUSIONS	Quartz monzonite, granodiorite quartz diorite

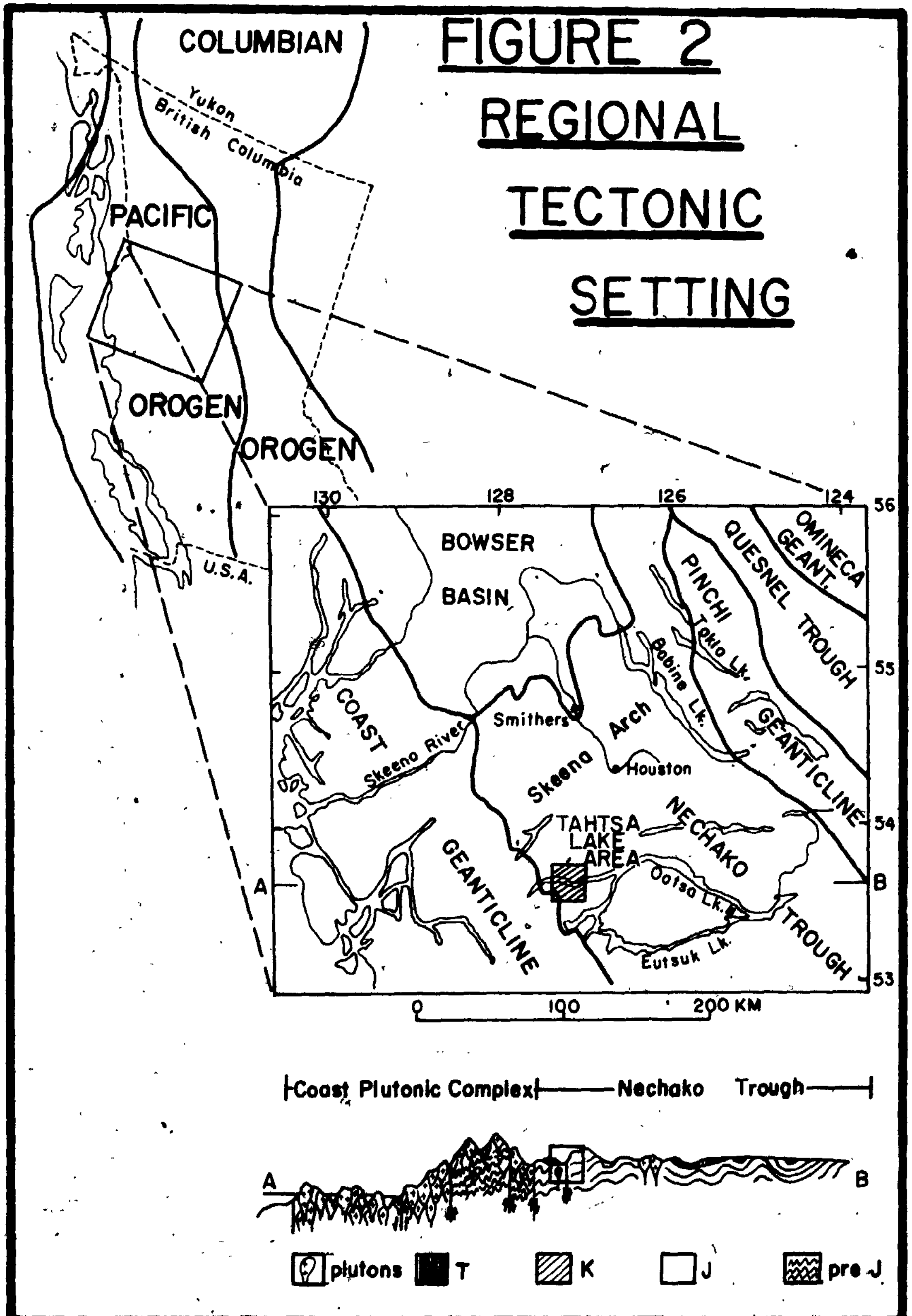


FIGURE 2
REGIONAL
TECTONIC
SETTING
COLUMBIAN
Yukon
British Columbia
PACIFIC
OROGEN
OROGEN
U.S.A.
130
128
126
124
56
55
54
53
BOWSER
BASIN
OMINECA
GEANT.
QUESNEL
TROUGH
PINCHI
Takla Lk.
Babine Lk.
GEANTICLINE
COAST
Skeena River
Smithers
Skeena
Arch
Houston
TAHTSA
LAKE
AREA
NECHAKO
Ootsa Lk.
Eutsuk Lk.
TROUGH
GEANTICLINE
A
B
0
100
200 KM
Coast Plutonic Complex
Nechako Trough
A
B
plutons
T
K
J
pre-J

Group rocks are unconformably overlain by a sequence of less deformed Lower Cretaceous (Albian) marine sedimentary rocks informally called Skeena Group (Figure 3). To the east of the Bowser Basin, continental sedimentary rocks of Upper Cretaceous age are exposed in the fault-bounded Sustut Basin. Relatively flat-lying continental volcanic rocks of Upper Cretaceous to Tertiary age outcrop in the vicinity of Ootsa Lake and constitute the Ootsa Lake Group. A younger sequence of volcanic rocks known as the Endako Group occurs north of Ootsa Lake. The eastern half of the Nechako Trough is largely covered by Tertiary plateau basalts.

The Nechako Trough has been the site of major episodes of plutonic activity from Upper Triassic to Tertiary time. Carter (1974) suggests these plutons can be subdivided using isotopically determined ages, chemical compositions, associated metal concentrations, and spatial distribution. Although most of the intrusions are Upper Cretaceous or Tertiary in age, a few older intrusions are also present. These are the Topley, Omineca, Francois Lake and Kitsault Intrusions which are Triassic to Late Jurassic in age. The Bulkley intrusions are Upper Cretaceous in age and define a north-trending belt occupying the core of Nechako Trough and extending southward into the Tahtsa Lake area (Figure 3). The Alice Arm and Nanika Intrusions are of Eocene age and parallel the eastern contact of the Coast Plutonic Complex. Several examples of

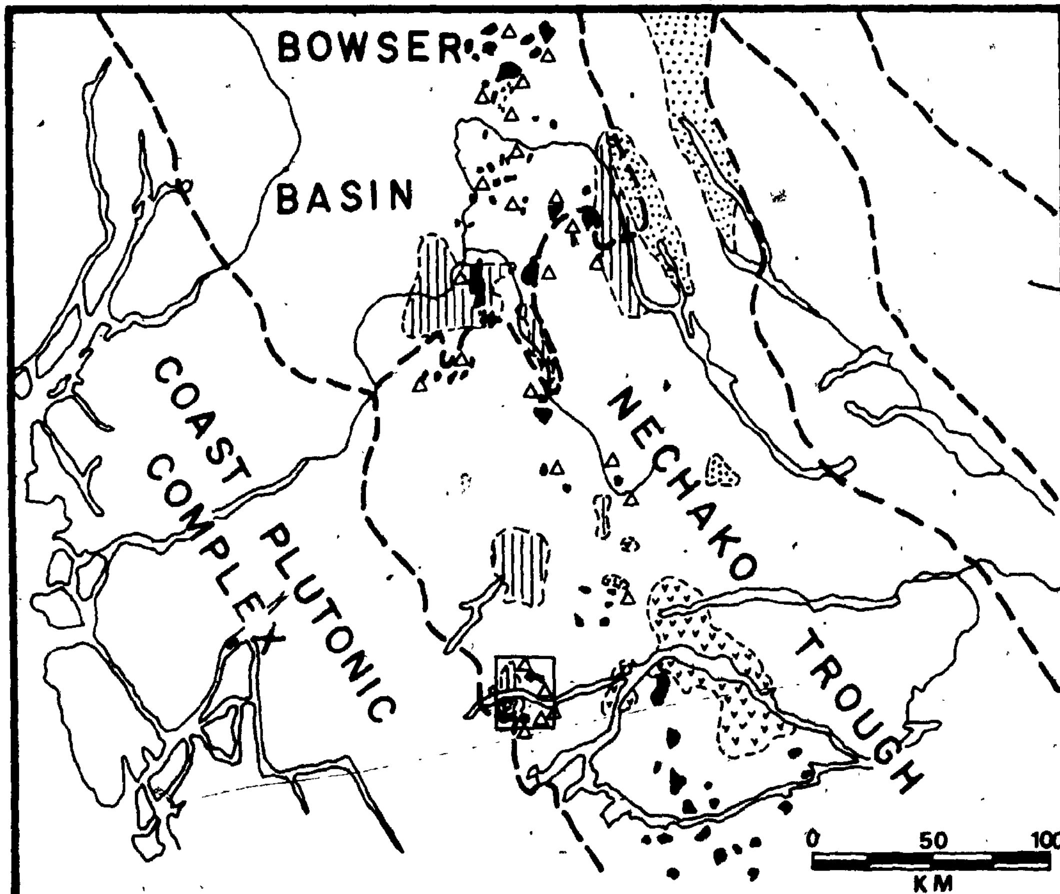


FIGURE 3. DISTRIBUTION OF CRETACEOUS ROCKS IN NECHAKO TROUGH

Upper Cretaceous-Paleocene

Ootsa Lake Group

Upper Cretaceous (70-84 m.y.)

Bulkley Intrusions
Δ = porphyry Cu, Mo

Upper Cretaceous

Sustut Group

Lower Cretaceous (Albian)

Skeena Group

these intrusions also occur in the Tahtsa Lake area. Babine Intrusions are also Eocene in age but are restricted to an area along the eastern edge of the Nechako Trough. Porphyry copper and molybdenum occurrences are associated with porphyritic phases of the Upper Cretaceous and Tertiary intrusions.

Although plutons of earliest Upper Cretaceous age abound in the Nechako Trough, only a few isolated areas of volcanic rocks of comparable age are known (Figure 3). Consequently, there is very little information on the nature of the volcanic cover that must certainly have been associated with emplacement of these plutons. A possible exception may be the Tahtsa Lake area where it appears that a considerable thickness of earliest Upper Cretaceous volcanic rocks have been preserved in downthrown fault blocks.

CHAPTER 3

GENERAL GEOLOGY OF TAHTSA LAKE AREA

3.1 General Statement

Volcanic and sedimentary rocks of Jurassic and Lower Cretaceous age underlie most of the Tahtsa Lake area (Table 2, Figure 4). These rocks are folded and faulted and are unconformably overlain by relatively flat-lying Upper Cretaceous volcanic rocks (Figure 4). The entire sequence is cut by plutons of Upper Cretaceous to Early Tertiary age, several of which have associated porphyry copper occurrences. The Upper Cretaceous rocks and associated mineral occurrences are the main focus of this thesis, and will be discussed separately in Chapter 4.

3.2 Pre-Upper Cretaceous Rocks

Hazelton Group

Distribution

The oldest rocks in the Tahtsa Lake area are Jurassic in age and belong to the Hazelton Group. These rocks outcrop in the eastern half of the map area as a terrane of glacially rounded hills and ridges (Figure 4). Good exposures also occur on the western slope of Tahtsa Range, and on the shores of Tahtsa and Troitsa Lake (Figure 23 in pocket).

Stratigraphy

In the Tahtsa Lake area, the Hazelton Group can be subdivided into a lower volcanic division and an upper marine sedimentary division (Table 3). The contact between

TABLE 2
TABLE OF FORMATIONS
TAHTSA LAKE AREA

PERIOD or Epoch	MAJOR SUBDIVISIONS	PREDOMINANT LITHOLOGIES
Pleistocene to Recent		Till, gravel, sand, clay alluvium
	UNCONFORMITY	
Eocene	Nanika Intrusions (44-54 m.y.)	Quartz monzonite, quartz latite
	INTRUSIVE CONTACT	
	Coast Intrusions (c.a. 50 m.y.)	Quartz diorite, diorite
	INTRUSIVE CONTACT	
U. Cretaceous to Tertiary	Dykes	Basalt, lamprophyre; porphyritic rhyodacite, dacite; andesite
	INTRUSIVE CONTACT	
	Mt. Bolom Stock and Related Dykes	Porphyritic biotite-hornblende granophyre
	NOT IN CONTACT	
U. Cretaceous	Bulkley Intrusions (75-83 m.y.)	Porphyritic and equigranular biotite-hornblende grano-diorite, quartz diorite, quartz monzonite. Includes minor porphyritic rhyodacite
	NOT IN CONTACT	
	Kasalka Intrusions	Hornblende-augite latite-andesite, hornblende-biotite-augite diorite, porphyritic dacite
	INTRUSIVE CONTACT	
	Kasalka Group	Lahar, latite-andesite; welded lapilli and crystal tuff; porphyritic dacite, rhyodacite, basal pebble conglomerate
	ANGULAR UNCONFORMITY	
L. Cretaceous (Albian)	Skeena Group	Lithic wacke, shale; amygdaloidal basalt minor flow breccia
	ANGULAR UNCONFORMITY	
M. Jurassic	Hazelton Group	Volcanic wacke, argillite: banded chert, rhyodacite, dacite, andesite; crystal, lithic and lapilli tuff

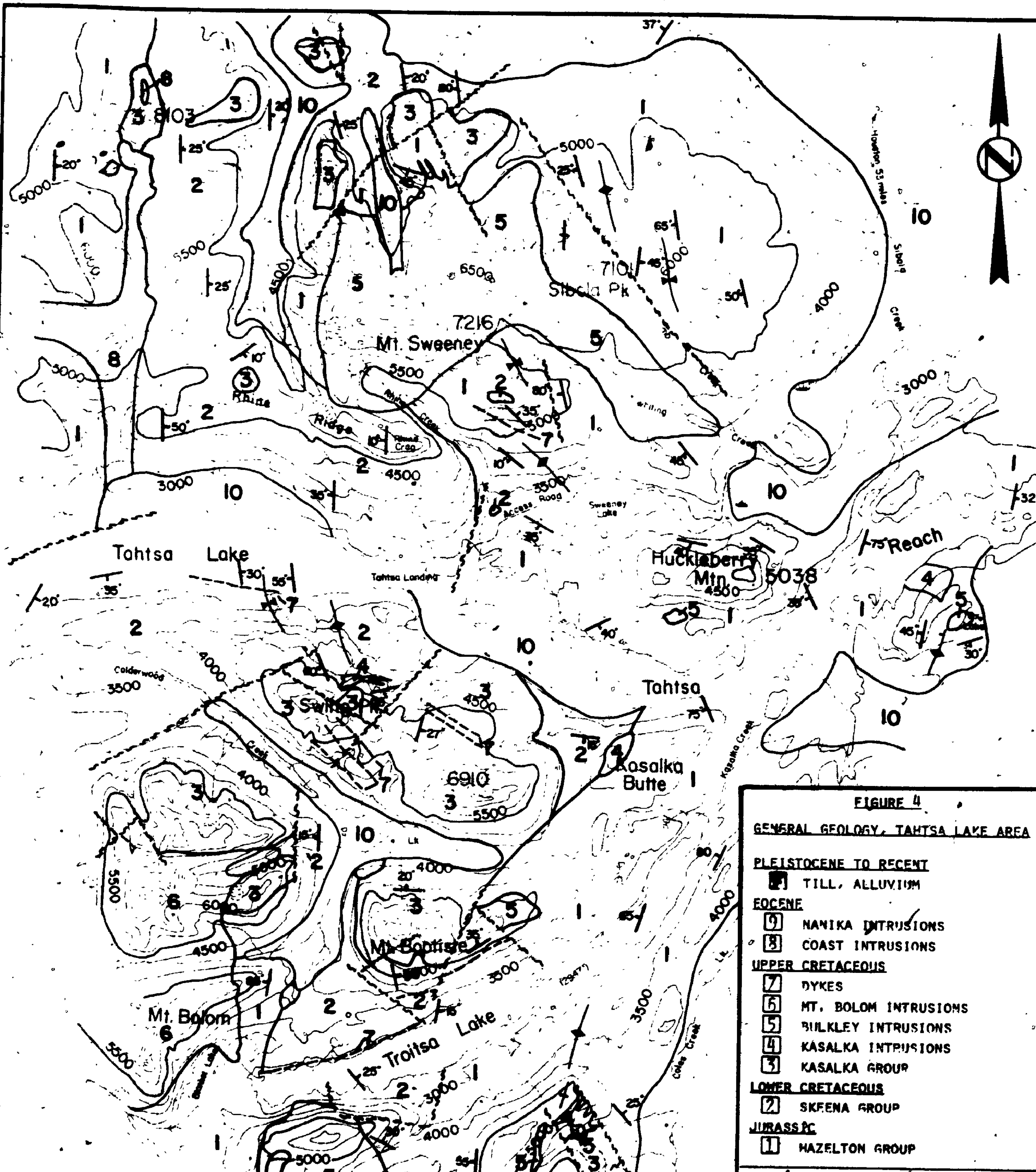


FIGURE 4
GENERAL GEOLOGY, TAHTSA LAKE AREA
PLEISTOCENE TO RECENT
TILL, ALLUVIUM
EOCENE
NANIKA INTRUSIONS
COAST INTRUSIONS
UPPER CRETACEOUS
DYKES
MT. BOLOM INTRUSIONS
BULKLEY INTRUSIONS
KASALKA INTRUSIONS
KASALKA GROUP
LOWER CRETACEOUS
SKEENA GROUP
JURASSIC
HAZELTON GROUP
BEDDING
FOLDS
FAULT
CONTACT
KM
Mt. Sweeney
Sibola Pk
Rhine Ridge
Tahtsa Lake
Tahtsa Landing
Sweeney Lake
Access Road
Huckleberry Mtn
Reach
Tahtsa
Kasalka Butte
Mt. Bolom
Troitsa Lake
Colderwood
Kasalka Creek
Coles Creek

these divisions is generally gradational, and conformable. Fault contacts are also common. Discontinuous lenses of rhyolitic volcanic and siliceous sedimentary rocks are common in the zone of transition between these major divisions. Duffell (1959) estimated the total thickness of the Hazelton Group in the Tahtsa Lake area to be 3.5 kilometers.

Lithology

Andesitic volcanic rocks at the base of the Hazelton Group are predominantly fragmental in nature and are characteristically red and green in color because of oxidation and chloritic alteration. Individual beds range from several centimeters (Plate 1B) to as much as 100 meters in thickness. The predominant rock types are lapilli-tuff, lithic tuff, crystal tuff and tuff-breccia (Plates 1A,C) with minor intercalations of porphyritic augite andesite and dacite flows, tuffaceous siliceous argillite, and pebble conglomerate. The fragmental rocks are poorly-sorted and contain mainly angular clasts of andesite and tuff with lesser amounts of chert and rhyolite. The matrix of fragmental rocks is largely composed of quartz and plagioclase crystal fragments cemented by sericite and microcrystalline silica.

Siliceous light grey, greenish grey and dark grey volcanic rocks conformably overlie, and are in part interbedded with red and green volcanic units of the Hazelton Group. These rocks are typically thin-bedded (Plate 2A), and in places are finely-laminated. The predominant rock

Plate 1

A Outcrop of tuff-breccia, Hazelton Group.

B Thin-bedded crystal and ash tuff, Hazelton Group.

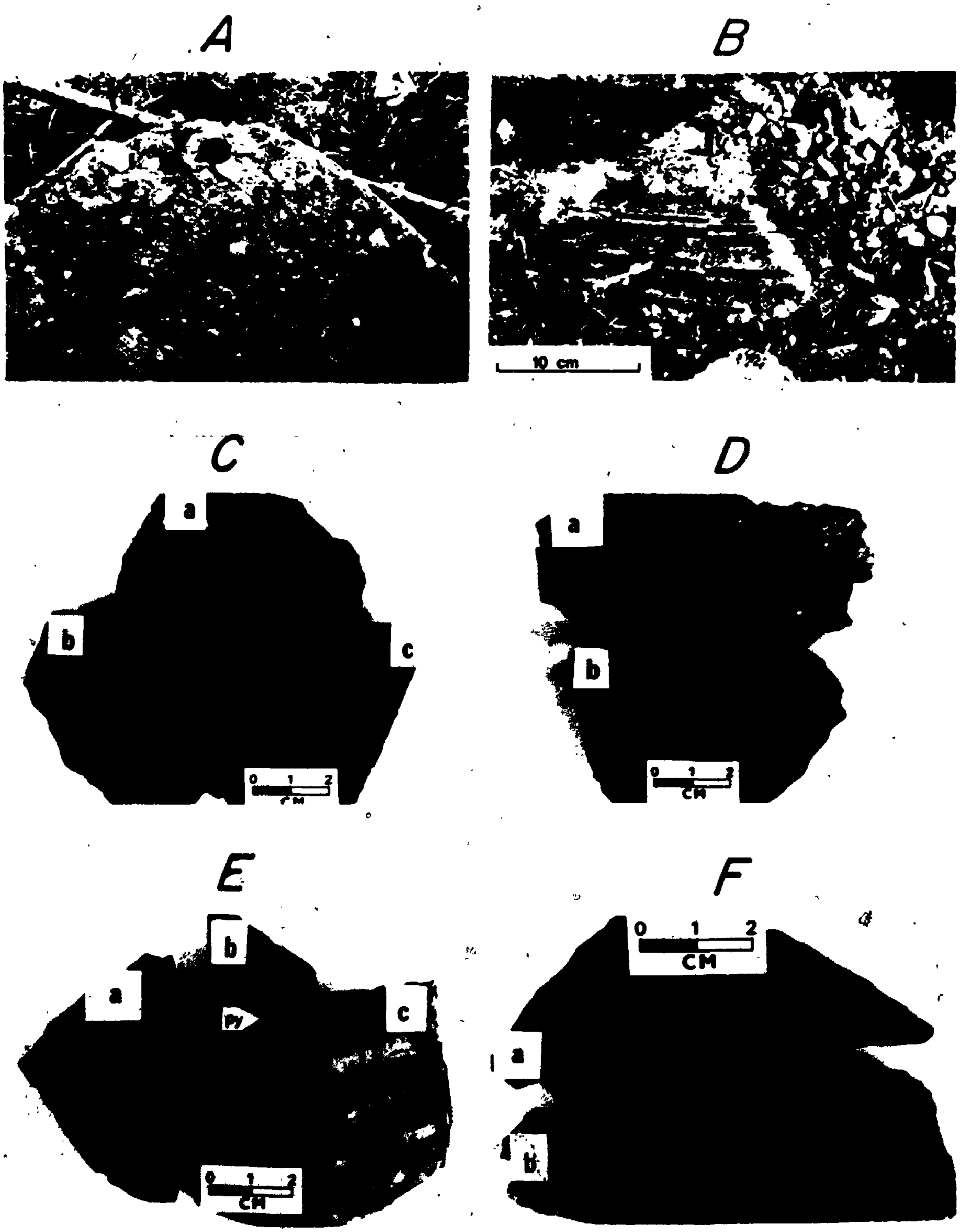
C Typical samples of red and green volcanic rocks of Hazelton Group.
(a) lapilli-tuff with andesite fragments; (b) slightly welded lapilli-tuff with dacite fragments; and (c) fine-grained ash tuff with graded bedding.

D Moderately-welded rhyolitic lapilli-tuff (a,b) of Hazelton Group. Note compressed nature of fragments.

E Banded (a,c) and mottled (b) chert interbedded with felsic pyroclastic units of Hazelton Group. Sample (b) contains abundant disseminated pyrite.

F Coarse volcanic wacke (a) and chert pebble conglomerate (b), Hazelton Group.

PLATE I



types are welded lapilli-tuff, mottled cherty tuff, and banded or massive dacite to rhyodacite flows (Plates 1D,E). Eutaxitic textures are common in the more siliceous fragmental rocks. (Plate 1D)

The transition from felsic pyroclastic rocks to marine sedimentary rocks is gradational and begins with increasing amounts of chert and siliceous argillite interbedded with the volcanic rocks. Stratabound lenses of pyrite and pyrrhotite, up to several centimeters thick, are common in this part of the section. These rocks grade upward into alternating beds of mottled and banded grey chert (Plate 1E) and siliceous argillite and siltstone. Above this horizon are up to 800 meters of interbedded dark grey pebble conglomerate, sandstone, argillite and minor tuff (Plate 1F). Shelly fauna, particularly large coiled ammonites, abound in the clastic sedimentary units. These rocks are poorly-sorted, consisting mainly of angular and subrounded clasts of andesite, siliceous argillite plagioclase and minor quartz set in a chlorite-clay matrix.

Age and Correlation

Duffell (1959) assigns a Middle Jurassic (Bajocian) age to the marine sedimentary rocks exposed in the vicinity of Tahtsa Lake. On the basis of this age, these rocks can be correlated with the marine sedimentary division of the Hazelton Group as recognized by Duffell (1959) and Tipper (1971) in other parts of West Central British Columbia

TABLE 3 HAZELTON GROUP SUCCESSION

AGE	WEST CENTRAL B. C. (Duffell, 1959; Tipper, 1971)	TAHTSA LAKE AREA
MIDDLE TO UPPER JURASSIC	UPPER VOLCANIC DIVISION Volcanic flows, tuffs breccias	
MIDDLE JURASSIC	MARINE SEDIMENTARY DIVISION Tuffaceous volcanic wacke, argillite, chert, pebble conglomerate, green tuff, impure limestone	Volcanic wacke, argillite, pebble conglomerate, minor tuff; Interbedded chert, siliceous argillite, rhyodacite Ignimbrite, siliceous tuff, porphyritic andesite, rhyolitic flow rocks, chert
LOWER JURASSIC	LOWER VOLCANIC DIVISION Red tuff unit: Red and maroon tuff, breccias minor sedimentary rocks. Red volcanic unit: Breccias, tuffs, ignimbrites, andesitic flows. Green volcanic unit: Green volcanic breccias, tuffs, minor flows.	Red and green lapilli-tuff tuff-breccia, andesitic flows, crystal tuff, minor argillite.

(Table 3). In the Tahtsa Lake area, red volcanic rocks underlying this division can be considered part of the Lower Volcanic Division. The Upper Volcanic Division of the Hazelton Group was not recognized in the map-area, but is known to be present in areas to the north and east (Duffell, 1959). If present, this division was removed by erosion in the Tahtsa Lake area prior to deposition of the Cretaceous rocks.

Skeena Group

Distribution

Sedimentary rocks of Lower Cretaceous age were first recognized in Tahtsa Lake area by Duffell (1959). These rocks are typical of the successor basin deposits of the Skeena Group. In the Tahtsa Lake area, these rocks are well exposed on the south shore of Tahtsa Lake, in the core of Tahtsa Range and on Swing Peak ridge (Figure 4).

Stratigraphy

Duffell (1959) suggested a twofold subdivision of the Lower Cretaceous succession into a lower sedimentary division and an upper volcanic division. However, examination of the contact between these divisions suggests that it is an angular unconformity, representing a major erosion surface. Furthermore, in several localities throughout the map area, the Lower Cretaceous sedimentary rocks conformably overlie green volcanic rocks which in turn appear to unconformably overlie Hazelton Group strata. These volcanic rocks are included as part of the Skeena Group

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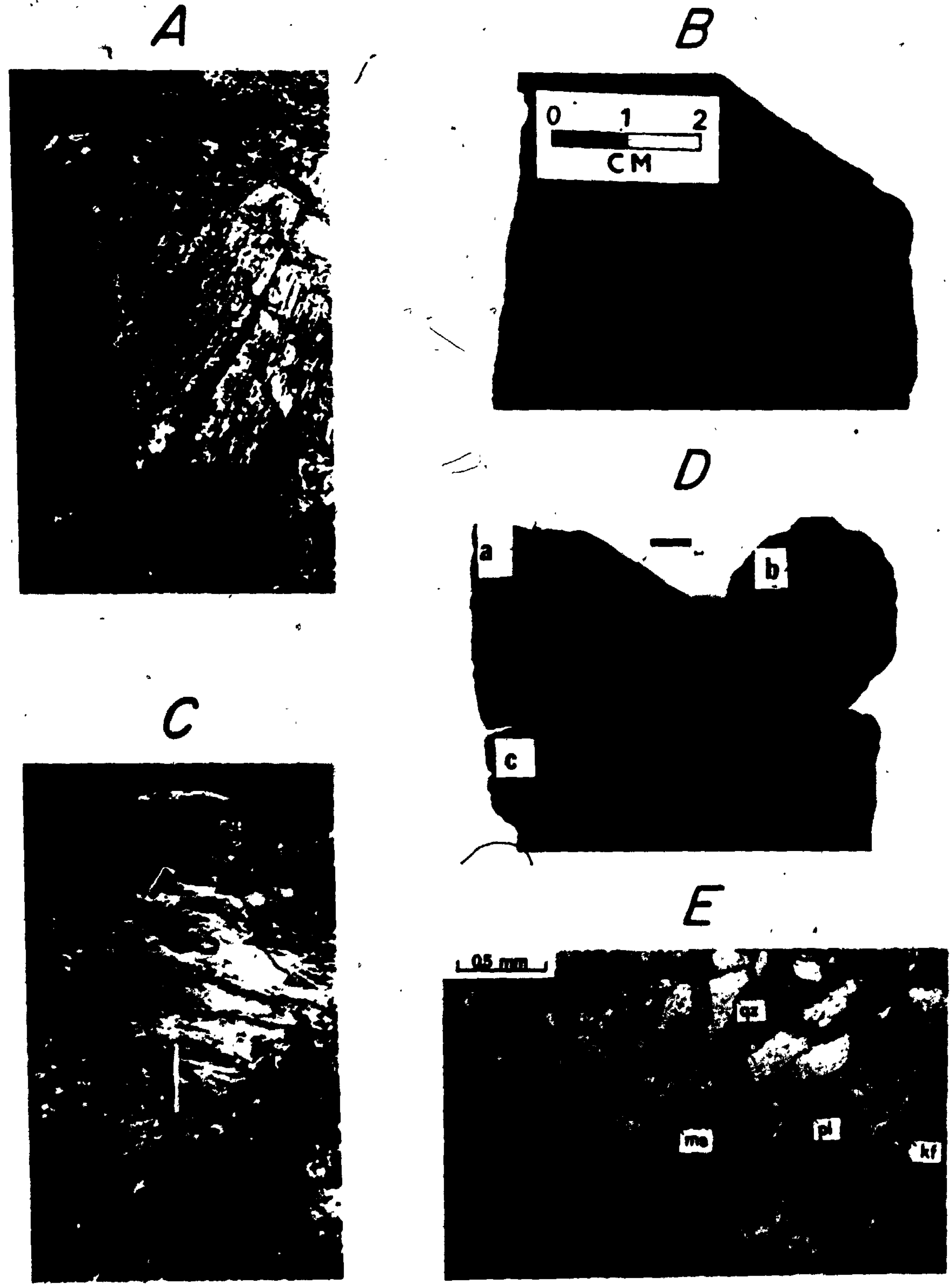
PLATE 2



which is estimated to be at least 1.5 Km thick in the Tahtsa Lake area.

The base of the Skeena Group is not well-exposed because the contact with older rocks is generally a fault. However, a relatively flat-lying conglomerate exposed on the east bank of Rhine Creek (near sample site M-46, Figure 25) appears to conformably underlie nearby flows of the Skeena Group, and as such, may be the basal member of the Lower Cretaceous succession.

Lithology

Massive volcanic flows at the base of the Skeena Group (Plate 2B) range from dark green to light grey in color and are characteristically amygdaloidal. Discontinuous lenses of flow breccia are common at the top of individual flows. The flows are mainly basalt in composition, containing euhedral tabular andesine and labradorite phenocrysts, up to 1 mm. long, set in a groundmass of divergent microlites of albite with interstitial chlorite, chloritic clay, calcite and granular magnetite. Primary pyroxenes are always pseudomorphed by chlorite with or without epidote. Amygdules are filled with concentric layers of calcite, chlorite, epidote and chalcedony, occasionally enclosing pyrite and pyrrhotite grains.

Amygdaloidal basalt is overlain by at least 1000 meters of interbedded sandstone and shale. These rocks are fawn grey to black in color and are arranged in beds ranging from 1cm to 50 meters in thickness. The predominant rock type is fawn to grey, fine-grained flaggy sandstone which commonly contains iron-rich concretions (Plate 2C,D) and carbonaceous plant fragments. Intercalations of shale are common, particularly near the base of the sedimentary division and these rocks locally contain poorly-preserved shelly marine fauna (Duffell, 1959). In places, the sandstone is intimately mixed with irregular discontinuous lenses and stringers of argillaceous material (Plate 2D) which is often disrupted by slumping, cross-bedding or organic activity.

The petrographic features of Lower Cretaceous and Middle Jurassic sandstone are compared in Table 4. The younger sandstone is readily distinguished from its older counterpart by its better sorting and greater content of microcline, muscovite and metamorphic rock fragments (Plate 2E).

Age and Correlation

Duffell (1959) assigns an Albian age to sedimentary rocks overlying the Hazelton Group in the Tahtsa Lake area. This age is based on marine invertebrate fossils collected from a small creek east of Swing Peak ridge. On the basis of age and lithology, these rocks can be correlated with the Haida Group on the Queen Charlotte Islands.

TABLE 4

COMPARISON OF MIDDLE JURASSIC AND LOWER CRETACEOUS SANDSTONES

RANGE OF MODES	HAZELTON GROUP M. JURASSIC	SKEENA GROUP L. CRETACEOUS
Plagioclase	15-30 %	7-14 %*
Quartz	6-13 %	23-35 %
Rock Fragments	25-40 %	19-31 %
Matrix	25-28 %	16-27 %
Microcline	nil	1-10 %
Biotite & Muscovite	nil	1-4 %
ROCK FRAGMENTS		
Chert and argillite, siliceous argillite	very common	very common
Volcanic	very common	very rare
Sedimentary	common	rare
Metamorphic	absent	common
Plutonic	very rare	common
MATRIX COMPOSITION	Mainly clay ± carbonate	Mainly clay and sericite Carbonate rare
SORTING	Poorly-sorted	Moderately well-sorted
ROUNDING OF GRAINS	Subangular to subrounded	Subrounded to rounded
NUMBER OF SAMPLES	19	38

* An 33-40

3.3 Post Upper Cretaceous Rocks

Coast Intrusions

Several plutonic bodies believed to be satellitic to the Coast Plutonic Complex, occur in the western part of the map area. The largest and most significant of these is the large north-trending dyke of quartz diorite which intrudes rocks of the Hazelton and Skeena Groups in the western part of the Tahtsa Range. This body is sometimes referred to as the Berg quartz diorite because of its proximity to the Berg porphyry copper deposit. There is no apparent disruption of regional structural trends near the dyke. Biotite hornfels is well-developed and extends up to 100 meters from the contact of the intrusion.

The Berg quartz diorite is texturally and compositionally-zoned with a mafic-rich, fine-grained border phase grading into coarser-grained more quartz-rich core. The rock is typically equigranular (Plate 8D), composed mainly of interlocking tabular laths of oscillatory-zoned andesine and labradorite crystals (Plate 8E). Elongate subhedral to euhedral poikilitic hornblende encloses plagioclase. Biotite is subordinate to hornblende and occurs as random anhedral grains. Border phases of the quartz diorite contain minor amounts of pyroxene, in part pseudomorphed by hornblende. The latter, in turn, is replaced by biotite, particularly near the younger Berg quartz-monzonite stock. Quartz and K-feldspar occupy interstices between the larger grains, and in places appear to be replacing plagioclase. Magnetite is a common accessory mineral. The quartz diorite is hydrothermally-altered near the Berg porphyry copper deposit, with sericite occupying plagioclase sites and pyrite replacing magnetite.

Quartz diorite of the Coast Intrusions is clearly distinguishable from quartz diorite associated with Bulkley Intrusions by containing more hornblende and somewhat less quartz. Furthermore, the modal composition of the Berg quartz diorite (Sutherland Brown, 1966) is very similar to the average values for quartz diorites of the Coast Plutonic complex (Hutchison, 1970). K-Ar isotopic age determinations confirm that the quartz diorite is approximately the same age as the eastern zone of the Coast Plutonic Complex, i.e. 50 m.y. (Carter 1974).

Nanika Intrusions

The term Nanika Intrusions is applied by Carter (1974) to a group of stocks of quartz monzonite composition which have K-Ar isotopic ages c.a. 5[illegible] m.y., i.e. Eocene. The only intrusions of this composition and age in the Tahtsa Lake area are located on the western slope of the Tahtsa Range at the Berg porphyry copper deposit (Figure 4). One of these intrusions is cut by a later northeast-trending dyke of porphyritic quartz latite (Figure 23 in pocket). A breccia zone occurs south of this stock.

The Berg biotite-hornblende quartz monzonite stock intrudes moderately east-dipping Hazelton Group pyroclastic rocks. Emplacement of the stock has not produced any major disruption of regional structural trends. A biotite hornfels contact metamorphic aureole encloses the stock and is superimposed on both Hazelton Group rocks and the quartz diorite to the east.

The Berg quartz monzonite is pinkish-grey, coarsely porphyritic rock (Plate 8B). In outcrop, the rock is rusty brown because of oxidation of abundant sulphide minerals. Phenocryst minerals constitute 35 to 50 per cent of the rock, primarily euhedral, oscillatory-zoned oligoclase and andesine up to 6 mm. in diameter. Smaller plates and books of biotite, elongate hornblende needles, anhedral corroded quartz eyes and scattered euhedral perthitic K-feldspar are also present. The groundmass is essentially a mosaic of microcrystalline quartz, orthoclase and plagioclase in varying proportions. Magnetite is rarely preserved in these rocks and is usually pseudomorphed by pyrite or goethite. The Berg quartz monzonite is readily distinguishable from quartz monzonite and granodiorite of Upper Cretaceous age by containing significantly more K-feldspar.

Northeast-trending dykes of porphyritic quartz latite occur within and marginal to the Berg quartz monzonite. The quartz latite is texturally similar to the quartz monzonite, containing a similar assemblage of phenocryst minerals. However, it is readily distinguished in thin section by a general lack of groundmass quartz. The modal quartz content of the quartz latite is apparently less than 10 per cent (Sutherland Brown, 1966). This rock type is generally unmineralized and apparently post dates formation of the Berg porphyry copper deposit.

3.4 Economic Geology

Seven major porphyry copper occurrences are known to be present in the Tahtsa Lake area. These occurrences are associated with porphyritic stocks and dykes of Upper Cretaceous and Eocene age (Figure 4). To date, none of these occurrences have advanced to the production stage. The largest and most significant of these deposits in terms of tonnage of ore grade material, is the Berg porphyry copper deposit located along the western margin of the map area. Here the intrusive host rock is quartz monzonite of the Eocene Nanika Intrusions. Ore grade material lies mainly to the east of the stock where extensive drilling has defined a major ore zone of undisclosed size, containing chalcopyrite and molybdenite in quartz veinlet stockworks. Molybdenite predominates in the marginal and contact zones of the stock grading outward into predominantly chalcopyrite in biotite hornfels (Sutherland Brown, 1966; Carter, 1974). A pyrite halo encloses the ore zone and extends up to 600 meters from the stock. Extensive oxidation and leaching of the ore zone has produced an irregular blanket of supergene enrichment. Other porphyry copper occurrences in the Tahtsa Lake area are genetically related to intrusions of Upper Cretaceous age and will be discussed in the following chapter.

In addition to porphyry copper occurrences, several

Pb-Zn-Ag veins also occur in the Tahtsa Lake area. The most significant of these is the now defunct Emerald Glacier Mine, located 2.2 kilometers southeast of Mt. Sweeney (Duffell, 1959). This deposit has been previously described as a northwest-trending, steeply-dipping shear zone occupying the crest of a monoclinal crumple in the Hazelton Group strata (Duffell, 1959). Ore minerals consist of Ag-bearing galena, sphalerite and minor chalcopyrite, in a gangue of quartz, minor calcite and wall rock. The vein is approximately 300 meters long and is more or less conformable to the bedding in the Hazelton Group rocks, occupying a stratigraphic position between felsic pyroclastic and sedimentary units. This vein may actually be sheared stratabound deposit of volcanogenic origin.

3.5 <u>Structure</u>

The Tahtsa Lake area has been subjected to a complex history of faulting and regional uplift related to evolution of the Pacific Orogen, and in particular, to formation of the Coast Geanticline to the west. The major structural elements in the area are high angle normal and reverse faults which bound uplifted, down-faulted and tilted blocks. Major thrust faults are not recognized, but may be present, particularly in older Hazelton Group rocks which lack suitable marker horizons for the recognition of such faults.

The predominant trend of faulting is northwest with subordinate northeast and north-trending faults, restricted to blocks bounded by the northwest faults. Trends of airphoto linears, measured fracture directions, and dyke trends, also have prominent northwest orientation with subordinate northeast trends (Figure 23 in pocket).

Anticlinal and synclinal fold structures occur in both the Hazelton and Skeena Group rocks. These folds have northerly trends in the north and south parts of the map area with a major swing to westerly trends around the perimeter of the Kasalka range. By contrast, folding of Upper Cretaceous volcanic rocks is restricted to tilting of fault blocks and gentle warping of strata.

CHAPTER 4

UPPER CRETACEOUS VOLCANIC AND PLUTONIC ROCKS

4.1 General Statement

Prior to the present study, volcanic or sedimentary rocks younger than Lower Cretaceous (Albian) were not known to be present in the Tahtsa Lake area. However, through detailed mapping of the area, it was discovered that the Skeena and Hazelton Groups were unconformably overlain by a sequence of volcanic rocks of earliest Upper Cretaceous age. These rocks are intruded by the Kasalka, Bulkley and Mt. Bolom intrusions and late northwest-trending dyke swarms, all considered to be Upper Cretaceous in age. Porphyry copper occurrences are associated with porphyritic phases of the Bulkley Intrusions. The crosscutting relationships of Upper Cretaceous volcanic and plutonic rocks are diagrammatically illustrated in Figure 5, and their areal distribution is presented in Figure 6.

4.2 Volcanic Rocks

Kasalka Group

Definition and Distribution

Upper Cretaceous volcanic rocks are well-exposed in the Kasalka Range where they underlie most of Swing Peak Ridge and Mt. Baptiste (Figure 4). North of the Kasalka Range, these rocks are restricted to outcrops capping peaks in the Tahtsa Range. Kasalka Group is a new name applied to these rocks to distinguish them from older and younger volcanic sequences in West Central British Columbia.

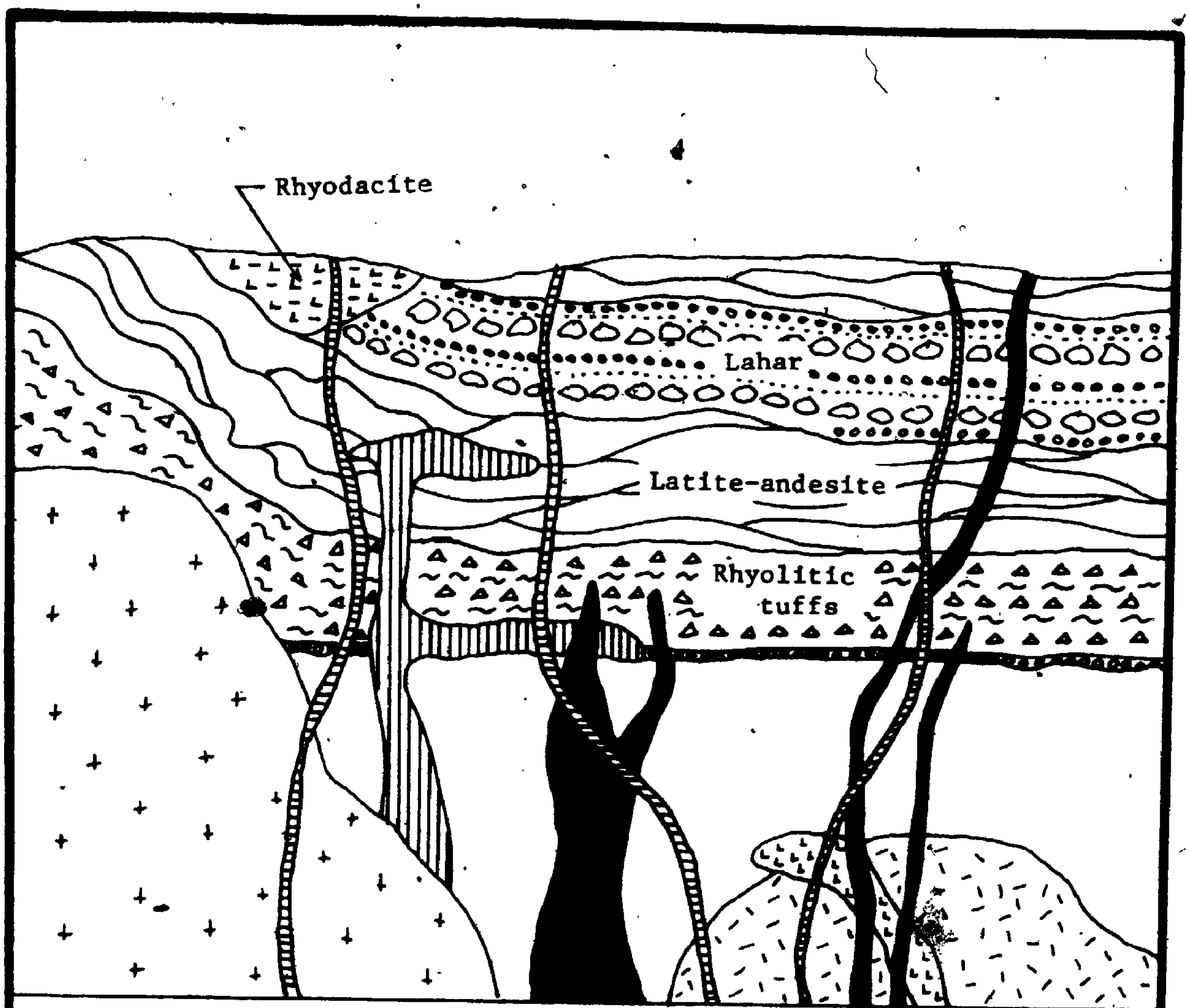


FIGURE 5. Diagrammatic illustration of cross-cutting relationships of Upper Cretaceous volcanic and plutonic rocks, Tahtsa Lake area.

Basalt, lamprophyre and andesite dykes

Mt. Bolom Stock - porphyritic granophyre

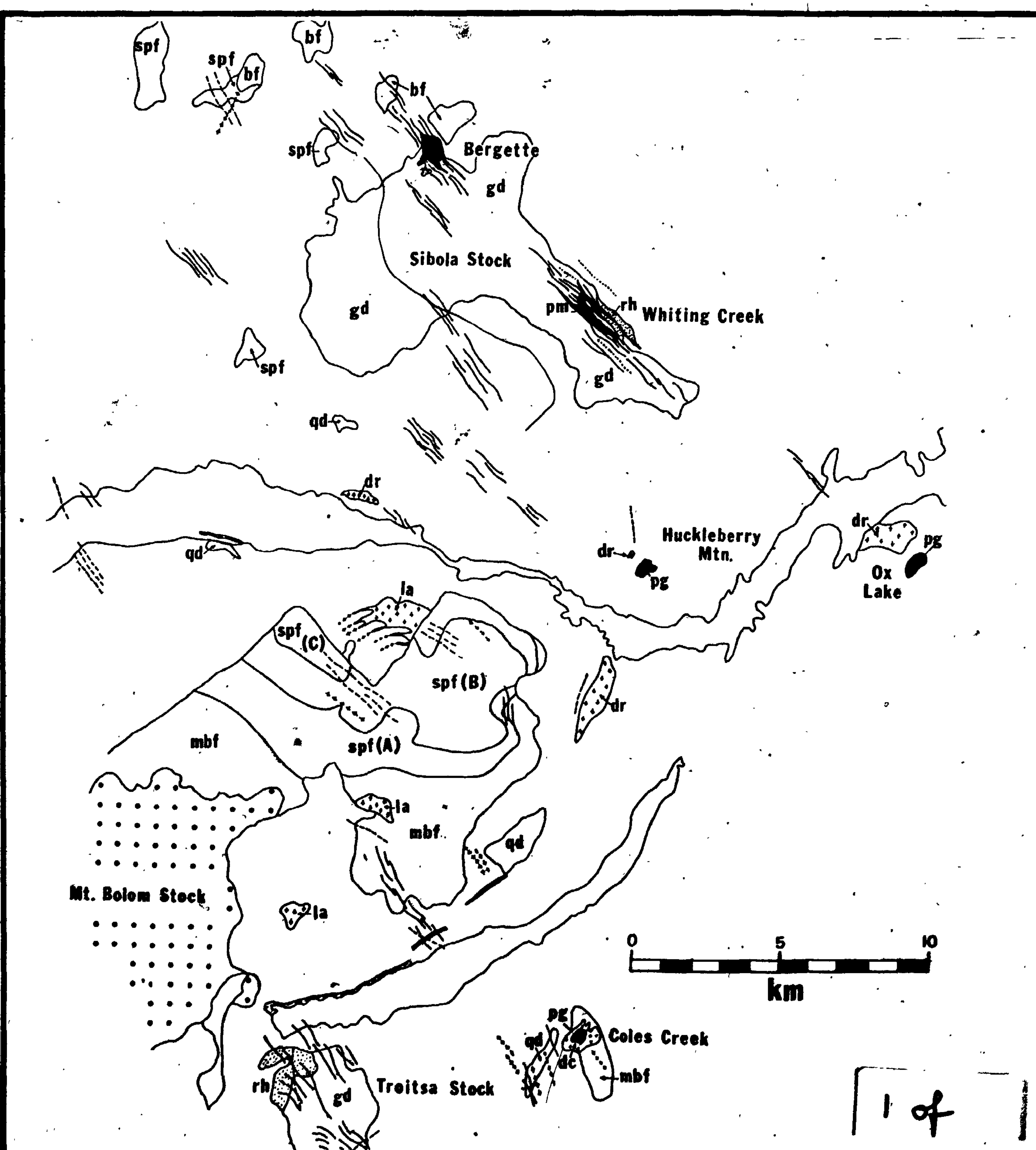
Bulkley Intrusions - porphyritic granodiorite

Bulkley Intrusions - porphyritic rhyodacite

Bulkley Intrusions - granodiorite

Kasalka Intrusions - latite-andesite, diorite,

Kasalka Group
Bergette Fm.
Swing Peak Fm.
Mt. Baptiste Fm.
Basal conglomerate


spf
spf
bf
bf
bf
spf
Bergette
gd
Sibola Stock
gd
pm
rh
Whiting Creek
spf
gd
qd
dr
qd
dr
pg
Huckleberry
Mtn.
dr
pg
Ox
Lake
la
spf
(C)
spf (B)
dr
mbf
spf(A)
la
mbf
qd
Mt. Bolom Stock
la
0
5
10
km
pg
qd
dc
Coles Creek
mbf
rh
gd
Troitsa Stock

D I

1 of

FIGURE 6

DISTRIBUTION OF UPPER CRETACEOUS VOLCANIC AND PLUTONIC ROCKS IN THE TAHTSA LAKE AREA

LEGEND

DYKE SWARMS

Rhyodacite, andesite, basalt and lamprophyre

MT. BOLOM INTRUSIONS

Porphyritic granophyre

BULKLEY INTRUSIONS

Porphyritic rocks: pg = granodiorite; pm = quartz monzonite

Porphyritic rhyodacite (rh)

Granitoid rocks: gd = granodiorite; qd = quartz diorite

KASALKA INTRUSIONS

Porphyritic latite-andesite (la); diorite (dr); porphyritic dacite (dc)

KASALKA GROUP

Bergette Formation (bf) - rhyodacite flows, minor tuff; Swing Peak Formation (spf) - spf(A) = member A, latite-andesite flows; spf(B) = member B, stratified lahar, minor flows; spf (C) = member C, latite-andesite flows Mt. Baptiste Formation (mbf) - rhyodacitic tuffs, flows, volcanic breccia, minor latite-andesite flows

Stratigraphy

The contact between the Kasalka Group and older rocks is an angular unconformity. Faulted contacts are also common, particularly on the north and northwest perimeter of the Kasalka Range. Where exposed, the contact with older rock is everywhere overlain by a relatively thin sequence of red to reddish-brown pebble conglomerate which is the basal member of the Kasalka Group. On Mt. Baptiste, this unit is overlain by up to 300 meters of felsic pyroclastic and flow rocks. Similar rocks outcrop at the base of Swing Peak Ridge where they are conformably overlain by up to 1000 meters of andesite flows and stratified volcaniclastic rocks (Plate 4C). Similar stratigraphic relationships are observed in the Tahtsa Range, although here individual units are much thinner and tend to pinch out to the north (Plates 5A,D). In this area, a younger sequence of rhyolitic flows unconformably overlie the andesitic volcanic rocks (Plate 5A).

On the basis of the stratigraphic relationships observed in the Kasalka and Tahtsa ranges, the following threefold subdivision of the Kasalka Group is proposed:

(1) Mt. Baptiste Formation: This Formation includes a complex mixture of rhyolite and subordinate andesitic pyroclastic and flow rocks which conformably overlie the basal pebble conglomerate. These rocks are restricted to the Kasalka Range.

Plate 3

A Outcrop of basal pebble conglomerate and sandstone of the Kasalka Group.

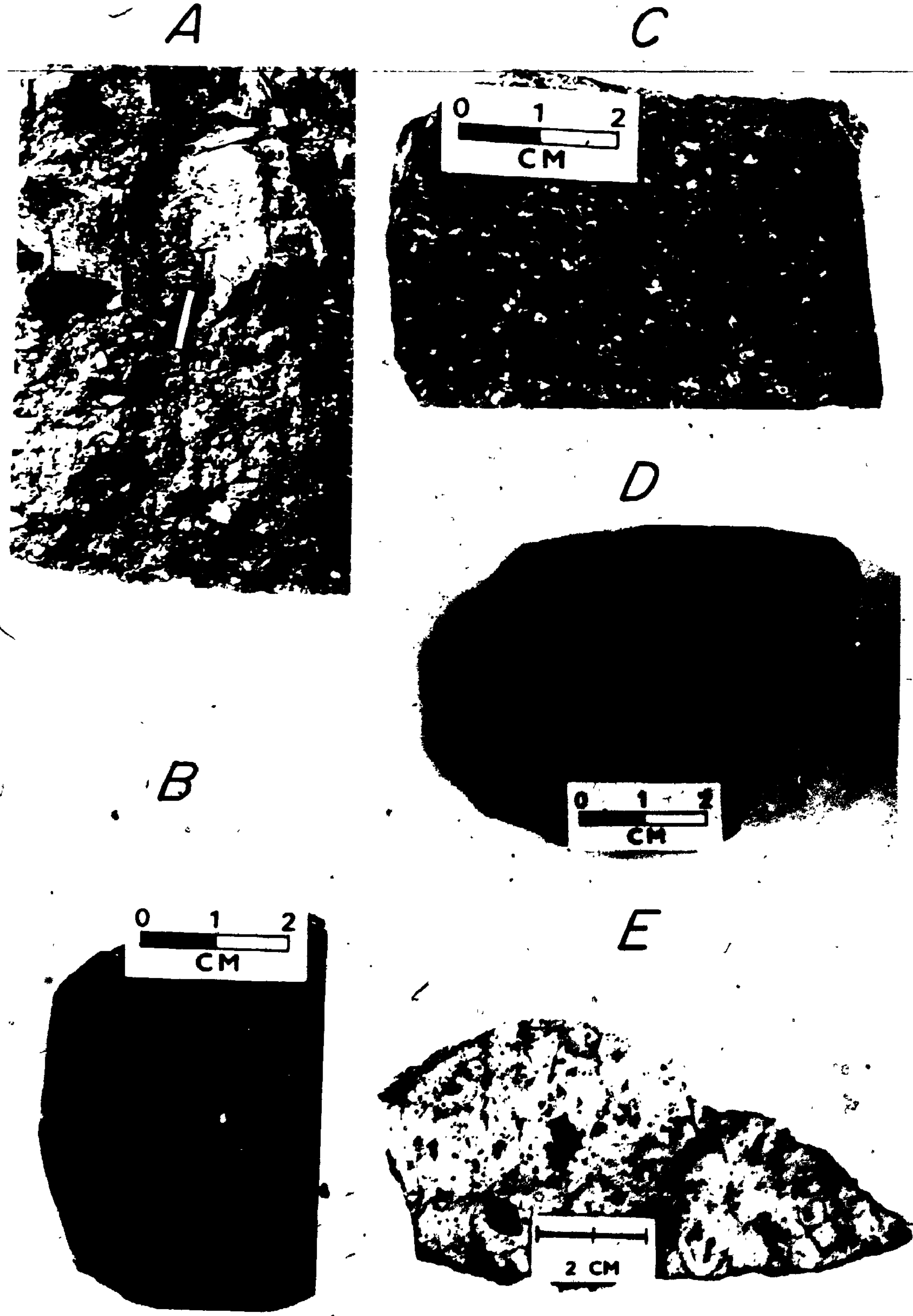
B Fragmental porphyritic dacite, Mt. Baptiste Formation, Mt. Baptiste.

C Moderately-welded rhyolitic ash flow tuff with eutaxitic foliation, Mt. Baptiste Formation, Swing Peak ridge.

D Non-welded rhyolitic lapilli-tuff, Mt. Baptiste Formation, Mt. Baptiste.

E Rhyolitic lapilli-tuff with pervasive argillic alteration of feldspars, Mt. Baptiste Formation, Coles Creek.

PLATE 3



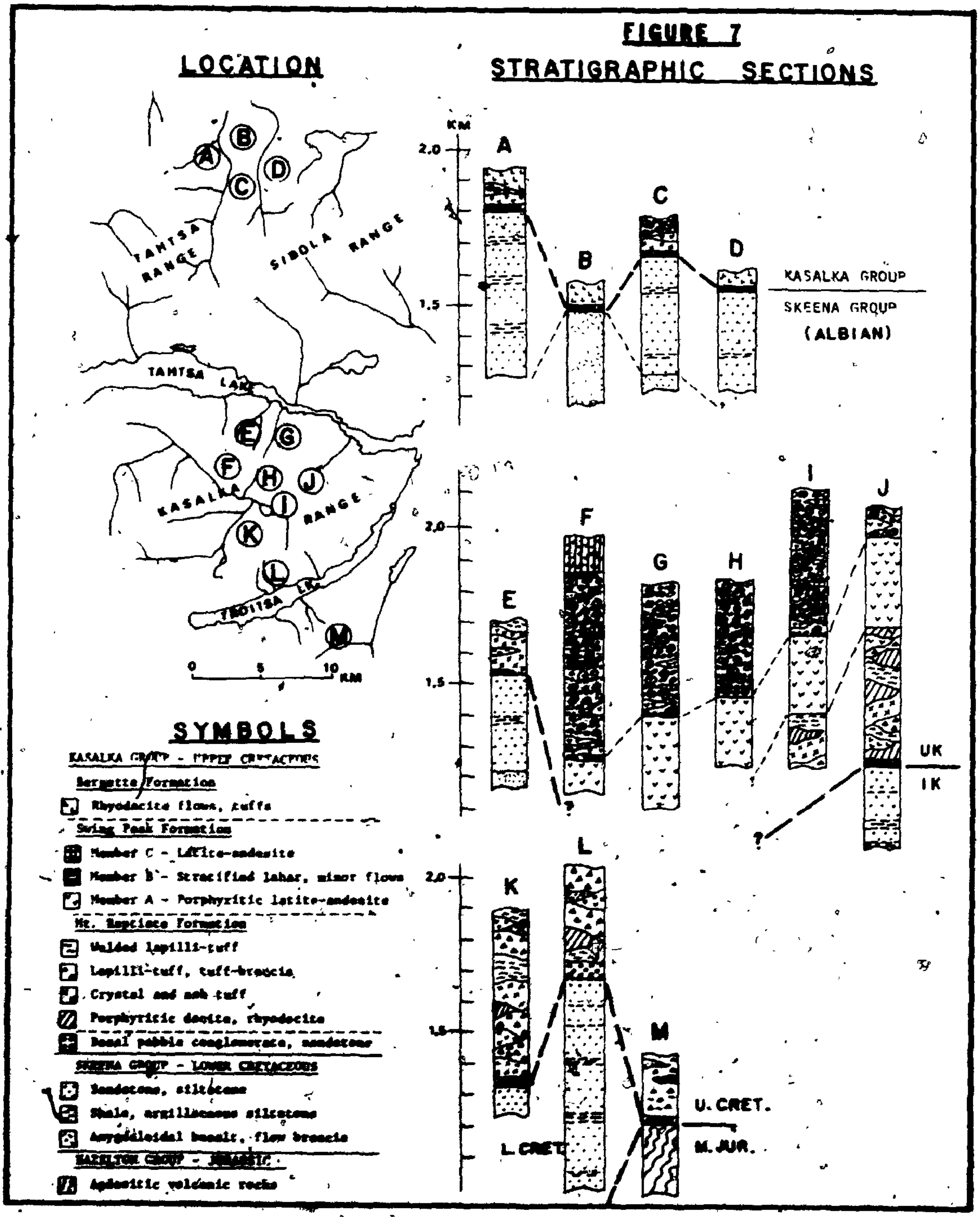
(2) Swing Peak Formation: This Formation includes a thick succession of flows and coarse clastic rocks (lahars) which conformably overlie the Mt. Baptiste Formation. The formation is divided into lower and upper members of massive andesitic flows, and a middle member of stratified lahar.

(3) Bergette Formation: This Formation includes rhyolitic flows which in part unconformably overlie the Swing Peak Formation. These rocks are restricted to the northern part of the Tahtsa Range.

Stratigraphic sections for the Kasalka Group are illustrated in Figure 7, and type sections are given in Appendix C. Maximum thickness of the Kasalka Group in the Kasalka Range is approximately 1500 meters, probably thinning to less than 200 meters in the Tahtsa Range. Nowhere in the Tahtsa Lake area is the top of the Kasalka Group exposed, and original thicknesses are uncertain.

Basal Conglomerate

The basal pebble conglomerate of the Kasalka Group is strikingly red in color and provides an easily recognizable marker horizon throughout the Tahtsa Lake area. Individual beds are of variable thickness and are conformable with overlying volcanic rocks. The basal conglomerate unit is generally between 5 to 10 meters thick, although it may thicken to 50 meters where it fills depressions in the underlying erosion surface. Lenses of red sandstone are locally


LOCATION
A
B
C
D
TAHTSA RANGE
SIBOLA RANGE
TAHTSA LAKE
E
G
F
H
J
I
K
L
M
KASALKA RANGE
TROITSA LK.
0 5 10 KM
FIGURE 7
STRATIGRAPHIC SECTIONS
KM
2.0
1.5
KASALKA GROUP
SKEENA GROUP
(ALBIAN)
UK
LK
U. CRET.
M. JUR.
L. CRET.
SYMBOLS
KASALKA GROUP - UPPER CRETACEOUS
Rhyodacite flows, tuffs
Swing Peak Formation
Member C - Latite-andesite
Member B - Stratified lahar, minor flows
Member A - Porphyritic latite-andesite
Welded lapilli-tuff
Lapilli-tuff, tuff-breccia
Crystal and ash tuff
Porphyritic dacite, rhyodacite
Basal pebble conglomerate, sandstone
SKEENA GROUP - LOWER CRETACEOUS
Sandstone, siltstone
Shale, argillaceous siltstone
Amygdaloidal basalt, flow breccia
Andesitic volcanic rocks

interfingered with the conglomerate. The pebble conglomerate is a poorly-sorted rock, containing rounded to subangular clasts of oxidized Hazelton and Skeena Group rock types set in a fine-grained sandy matrix cemented with iron oxide and silica (Plate 3A).

Mt. Baptiste Formation

The Mt. Baptiste Formation consists mainly of stratified grey to cream-colored siliceous pyroclastic rocks, which have various degrees of welding (Plates 3C,D,E). Individual beds range from a few meters to as much as 100 meters in thickness, with considerable variation in rock type from bed to bed. Locally, large blocks and bombs disrupt the stratification. The predominant rock type of the Mt. Baptiste Formation, following the classification scheme of Fisher (1966), is a partly welded to non-welded lithic lapilli-tuff (Plate 3D,E). Fragments in these rocks are generally angular, somewhat compressed and are mainly rhyolitic to dacitic in composition. Dark grey clasts of Hazelton Group andesitic volcanic rocks are also common. The groundmass of the lapilli-tuffs is predominantly microcrystalline quartz, muscovite and feldspar which in places contains minute devitrified glass shards.

Interbedded with the lapilli-tuffs of the Mt. Baptiste Formation are massive flows of fragmental and porphyritic rhyodacite, dacite (Plate 3B) and latite-andesite, densely-welded crystal tuff (Plate 3C), tuff-breccia and minor amounts of volcanic sandstone. The porphyritic flows contain

Plate 4

A Photomicrograph of latite-andesite (member A) of the Swing Peak Formation. Note the tabular phenocrysts of andesine (pl) and hornblende (hb) set in a finer-grained groundmass of plagioclase microlites with interstitial quartz and K-feldspar. X-nicols, Sample M-177.

B Outcrop of stratified lahar (member B) of the Swing Peak Formation, Swing Peak ridge. Note alternating beds of fine and coarse-grained material.

C The contact between latite-andesite flows (member A) and overlying stratified lahar (member B) of the Swing Peak Formation, south slope of Swing Peak Ridge.

D A typical sample of latite-andesite (member A) of the Swing Peak Formation. Note fine-grained porphyritic texture.

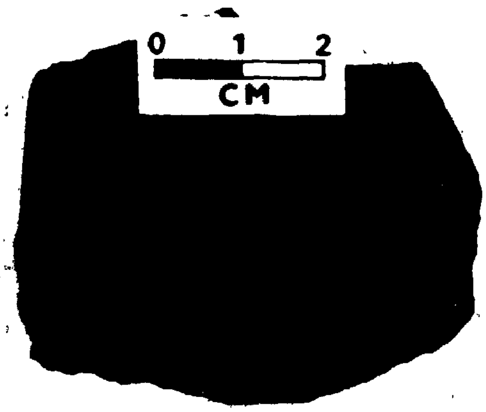
E Erosion surface of a flat-lying bed of coarse lahar, Swing Peak Formation, Swing Peak ridge. Note the size of boulders of latite-andesite contained in the lahar. Rock hammer for scale.

PLATE 4

A

C

D



B

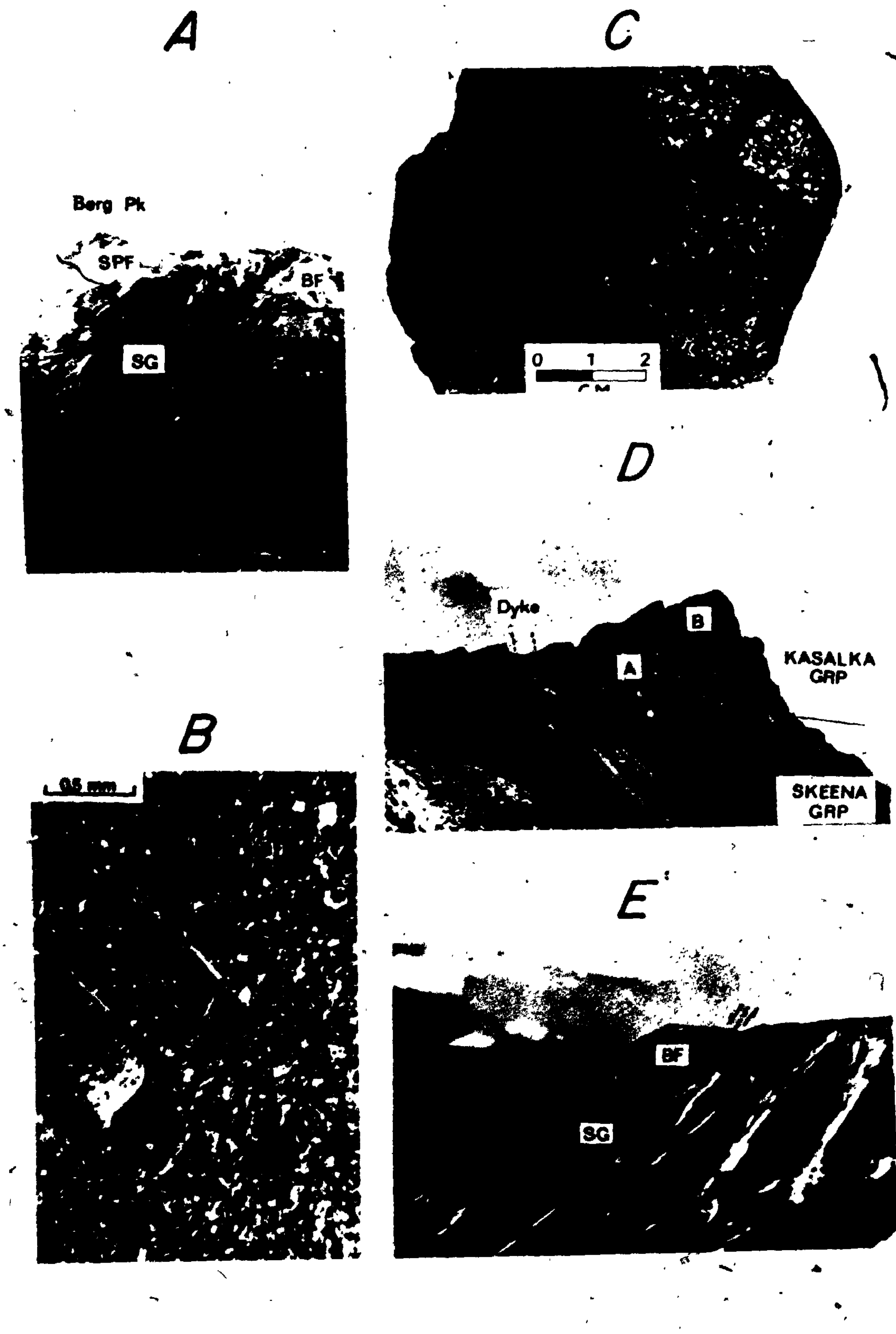
E

euhedral oscillatory-zoned andesine, brown biotite, with or without augite, green hornblende and in the more siliceous rocks, embayed quartz phenocrysts, all set in a microcrystalline to cryptocrystalline groundmass of quartz, K-feldspar and minor plagioclase. Minute phenocrysts of apatite, angular quartz and feldspar crystals and rhyolitic rock fragments, are also common in these rocks. By contrast, aphanitic rhyodacite flows are essentially alternating layers of quartz, K-feldspar and plagioclase microlites with few or no rock or crystal fragments. Alteration of plagioclase to epidote and chloritization of mafic minerals is present in all rocks of the Mt. Baptiste Formation.

Swing Peak Formation

The lower (A)and upper (C) members of the Swing Peak Formation are essentially massive, greenish-grey to dark green, fine-grained flows of andesitic to dacitic composition (Figure 7). Columnar jointing is well-developed in the upper member which caps the western end of Swing Peak ridge. The flows are typically porphyritic, containing euhedral plagioclase (An 35-50), hornblende and augite phenocrysts set in a microgranular or pilotaxitic groundmass of plagioclase with interstitial K-feldspar and minor quartz (Plates 4A,D). Moderate to intense alteration of plagioclase to clay, with or without epidote, and alteration of mafic minerals to fine-grained mixture of chlorite, microcrystalline quartz and iron oxide is ubiquitous in member A, but is only locally present in member C. Following

PLATE 5



A
B
C
D
E
Berg Pk
SPF
BF
SG
0.5 mm
0 1 2
Dyke
B
A
KASALKA GRP
SKEENA GRP
BF
SG

the classification scheme of Streckeisen (1967), flows of the Swing Peak Formation would be classified as latite-andesites or dacites, generally containing too much K-feldspar to be true andesites.

Andesitic flows at the base of the Swing Peak Formation (member A) are conformably overlain by a chaotic assemblage of volcanic debris up to 600 meters thick. These rocks are crudely stratified with alternating coarse and fine-grained units (Plate 4B). Clasts are generally rounded to subangular and range from a few centimeters up to several meters in diameter (Plates 4E, 5C). Most of the clasts are of porphyritic volcanic rocks indentical to member A of the Swing Peak Formation. These are suspended in a fine-grained muddy matrix which contains abundant angular plagioclase and quartz crystals. Thin, discontinuous beds of crystal tuff, volcanic sandstone, tuff-breccia and andesite, are interbedded with the coarse clastic units. Rocks of member B of the Swing Peak Formation are characteristic of rocks classified as lahar (Lydon, 1968).

Bergette Formation

The Bergette Formation consists of light grey to cream-colored rhyolite flows and fine-grained siliceous tuffs. These rocks cap the peaks to the north and northwest of the Bergette porphyry copper prospect where they unconformably overlie the Swing Peak Formation, or lie directly on the basal pebble congomerate (Plates 5A,E). Outcrops of the Bergette Formation are highly-fractured and covered by angular talus fragments. The rhyolitic flows are essentially microcrystalline aggregates of quartz, K-feldspar, muscovite and albite (Plate 5B), very similar to the flows of the Mt. Baptiste Formation. The modal composition of these flows is that of rhyodacite according to the classification scheme of Streckeisen(1967).

Age and Correlation

The Kasalka Group volcanic rocks are assigned an earliest Upper Cretaceous age because:

(1) The Kasalka Group unconformably overlies sedimentary rocks containing latest Lower Cretaceous (Albian) fauna (Duffell, 1959).

(2) At Coles Creek, a porphyritic stock with a K-Ar isotopically determined age of 83.4 m.y. (earliest Upper Cretaceous) intrudes the base of the Kasalka Group.

(3) K-Ar isotopic age determinations for whole rock samples of flows from the Mt. Baptiste and Swing Peak Formation indicated ages of 105 ± 5 and 87$\pm$ 4 m.y., respectively (Appendix D).

Considering the stratigraphic position of the group, and the fact that it is separated from older Albian rocks by a major erosion surface, a strictly Upper Cretaceous age is favored regardless of the 105 m.y. apparent age (Albian) determined for a whole rock sample of the Mt. Baptiste Formation.

Volcanic rocks of similar age and lithology to the Kasalka Group are rare in other parts of West Central British Columbia. Possible units with which these rocks may correlate are the Tip Top Hill volcanic rocks of the Parrott Lake area (Church, 1970), and the Brian Boru Formation of the Hazelton area (Sutherland Brown, 1960). The former are described as porphyritic andesite, dacite and rhyolite flows and have been dated by the K-Ar isotopic method at 77 m.y. (Carter, 1974). Brian Boru flows are also very similar to those of the Kasalka Group and may be of a similar age. On the basis of apparent age and lithology, the Kasalka Group may correlate with the Mt. Nansen and Hutshi groups in the Yukon Territory and with the Kingsvale group in Southern British Columbia.

4.3 Plutonic Rocks

Volcanic and sedimentary rocks of Jurassic to earliest Upper Cretaceous age are intruded by a wide variety of plutonic rock types. Mapping and petrographic studies suggest that these rocks can be subdivided on the basis of modal composition, isotopically-determined age and mode of occurrence (Table 5). Group names conform to those used by Carter (1974) where noted. The distribution of members of these groups with respect to volcanic rocks of the Kasalka Group is illustrated in Figure 6. The classification used for plutonic rocks is that of Bateman, et.al., 1963.

Kasalka Intrusions

The term Kasalka Intrusions is applied to a group of intrusions which are compositionally similar to volcanic

TABLE 5. Summary of Upper Cretaceous plutonic rocks present in the Tahtsa Lake area.

Subdivision	Age (K-Ar)	Rock Type and Mode of Occurrence	QZ	KF	PL	BT	HB	PX	MS
			Average Modal Composition						
DYKES	U. Cretaceous to Tertiary	Porphyritic rhyodacite dykes	60	20	10	1	-	-	10
		Also andesite, basalt, lamprophyre, NW dyke swarms							
MT. BOLOM INTRUSIONS		Porphyritic granophyre stock and dykes	25	21	45	2	4	-	-
BULKLEY INTRUSIONS (Carter, 1974)	U. Cretaceous (75-83 m.y.)	Porphyritic quartz monzonite dykes and irregular stocks	30	21	37	5	6	-	-
		Porphyritic rhyodacite dykes, sills, plugs	70	10	5	-	-	-	15
		Porphyritic granodiorite, small circular stocks	21	19	42	9	4	-	-
		Granodiorite, large compositionally-zoned stocks	21	19	48	4	6	-	-
		Quartz diorite, border phase of granodiorite stocks. smaller stocks and dykes	26	5	51	-	7	-	-
KASALKA INTRUSIONS (this study)		Porphyritic dacite, laccoliths, dykes	25	15	50	5	5	-	-
		Porphyritic latite-andesite subvolcanic dykes, sills, stocks	10	5	65	-	5	2	-
		Diorite stocks, dykes	10	5	60	5	5	2	-

Abbreviations: QZ = quartz; KF = K-Feldspar; PL= plagioclase; BT = biotite; HB = hornblende; PX = pyroxene; MS = muscovite.

rocks of the Kasalka Group. Volcanic rock names are used for the fine-grained intrusions because they have textural features characteristic of volcanic rocks, e.g., pilotaxitic groundmass, etc. Three major rock types are recognized and include: (1) porphyritic latite-andesite, (2) porphyritic dacite, and (3) diorite.

Porphyritic Latite-Andesite

Subvolcanic dykes, sills and small irregular stocks of porphyritic latite-andesite are common in the Kasalka and Tahtsa Ranges. (Plate 6A) Locally, these intrusions grade into tuff-breccia dykes, particularly on Swing Peak ridge. On the north slope of Swing Peak ridge, a series of latite-andesite sills radiate outward from a small stock and intrude strata of the Skeena and Kasalka Groups. Contacts are sharp and rarely have evidence of contact metamorphism. Bedding attitudes in the Skeena Group diverge from regional trends in the crosscutting intrusions.

Intrusive hornblende-augite latite-andesite is a fine-grained, green to dark grey porphyritic rock, petrographically identical to latite-andesite of the Swing Peak Formation (Plate 6D). In general, the intrusions have somewhat less chloritic alteration of mafic minerals than extrusive equivalents, quite often containing fresh augite and hornblende phenocrysts and abundant magnetite. Albite, clay and epidote alteration of plagioclase is locally intense.

Porphyritic Dacite

Sills and laccoliths of porphyritic dacite are common within the Mt. Baptiste Formation. An intrusive origin for

Plate 6

A Outcrop of a tuff-breccia dyke cutting the Swing Peak Formation, Swing Peak Ridge. Note the angular nature of the porphyritic latite-andesite clasts.

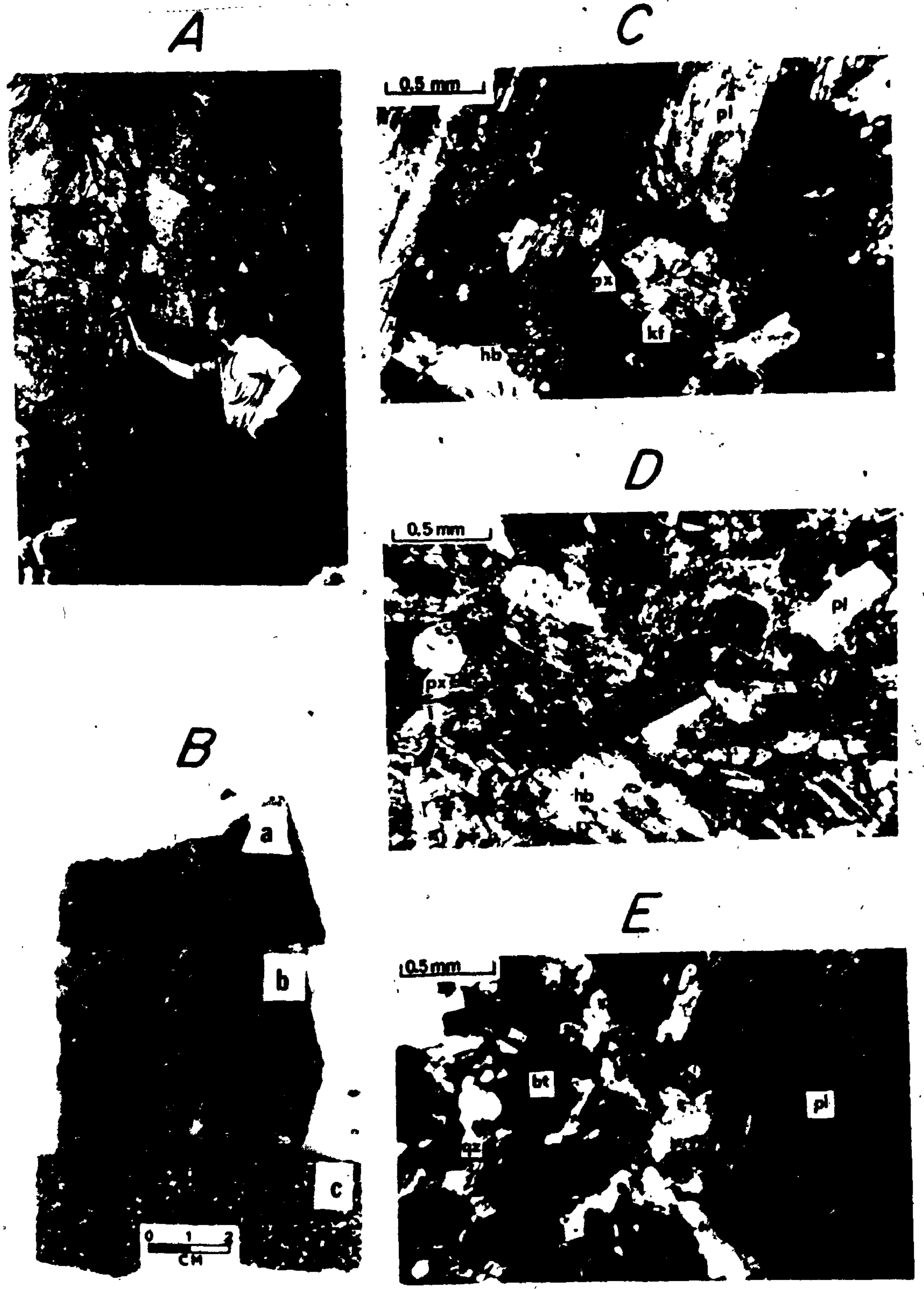
B. Three phases of the Sibola Stock- (a) quartz diorite border phase, (b) main phase hornblende-biotite granodiorite, and (c) late porphyritic quartz monzonite dyke.

C Photomicrograph of medium-grained diorite of the Kasalka Intrusions. Note the arrangement of subhedral crystals of plagioclase (pl), twinned pyroxene (px), hornblende (hb), and interstitial K-feldspar (kf). X- nicols, sample M-62.

D Photomicrograph of a latite-andesite dyke of the Kasalka Intrusions. Note the euhedral pyroxene (px), hornblende (hb) and plagioclase (pl) phenocrysts set in a microgranular groundmass of plagioclase and minor quartz. Also, note the similarity of the texture of this sample to that of the latite-andesite flow in Plate 4A. X-nicols, sample D-44.

E Photomicrograph of a typical sample of quartz diorite of the Bulkley Intrusion. Note the large zoned plagioclase (pl) phenocryst set in a medium-grained granular groundmass of quartz (qz), biotite (bt), plagioclase and minor K-feldsapr. X-nicols, sample BZ-14, Coles Creek.

PLATE 6



these bodies is not always obvious from field relationships and many may actually be flows within the volcanic succession. Porphyritic dacite dykes are also common in rocks which lie stratigraphically below the Kasalka Group, and these may be feeders to overlying intrusive and extrusive bodies. Perhaps the best exposures of porphyritic dacite are in creeks cutting the eastern slope of the ridge west of Coles Creek. Here, the dacite appears to be a relatively flat-lying laccolith with radiating dyke-like extensions (MacIntyre, 1974), cutting both Hazelton and Kasalka Group strata (Figure 8B).

Intrusive dacite is a fine-grained, medium grey to dark grey siliceous rock. The most characteristic feature of this rock type is the presence of bipyramidal, rounded and embayed quartz phenocrysts (Plate 7A). In addition, phenocrysts of euhedral andesine, plates of biotite and minor euhedral hornblende are present, all set in a microgranular to granular groundmass of equal proporitons of quartz, plagioclase and K-feldspar. Plagioclase and quartz also occur as angular fragments of shards.

Diorite

Small elongate stocks of diorite composition intrude Hazelton Group rocks at the western end of Kasalka Butte and on the ridge northwest of Ox Lake. Finer-grained equivalents of these stocks occur as dykes on Mt. Baptiste, where they cut both Jurassic and Lower Cretaceous strata. Small scale folding and pervasive fracturing of wallrocks occurs within 20 meters of the contacts of these intrusions.

Diorites of the Kasalka Intrusions are coarse to medium-grained, dark greenish-grey, equigranular to subporphyritic rocks composed of a mesh of interlocking, oscillatory-zoned andesine phenocrysts with intersertal augite, hornblende and biotite (Plate 6C). Minor K-feldspar and quartz occupy the interstices between the larger grains. The diorite has a modal composition somewhat similar to the andesitic rocks of the Kasalka Group, with the exception that it contains biotite as well as hornblende and augite. These minerals are usually partly to completely pseudomorphed by chlorite. Albite and clay alteration of plagioclase is also widespread. Primary magnetite is restricted to the least altered samples and is replaced by hematite where oxidation has occurred.

Bulkley Intrusions

The Bulkley Intrusions, as defined by Carter (1974), are granodioritic stocks and dykes of earliest Upper Cretaceous age (70-84 m.y.). In the Tahtsa Lake area, four major subdivisions of the Bulkley Intrusions are recognized. There are (1) small isolated stocks of porphyritic granodiorite such as the Coles Creek, Huckleberry Mountain and Ox Lake stocks, (2) large compositionally-zoned intrusions of equigranular granodiorite and quartz diorite such as the Sibola and Troitsa stocks, (3) dykes and sills of rhyodacite composition within and peripheral to (2), and (4) late porphyritic quartz monzonite dyke swarms cutting both (2) and (3). The areal distribution of these rocks is shown

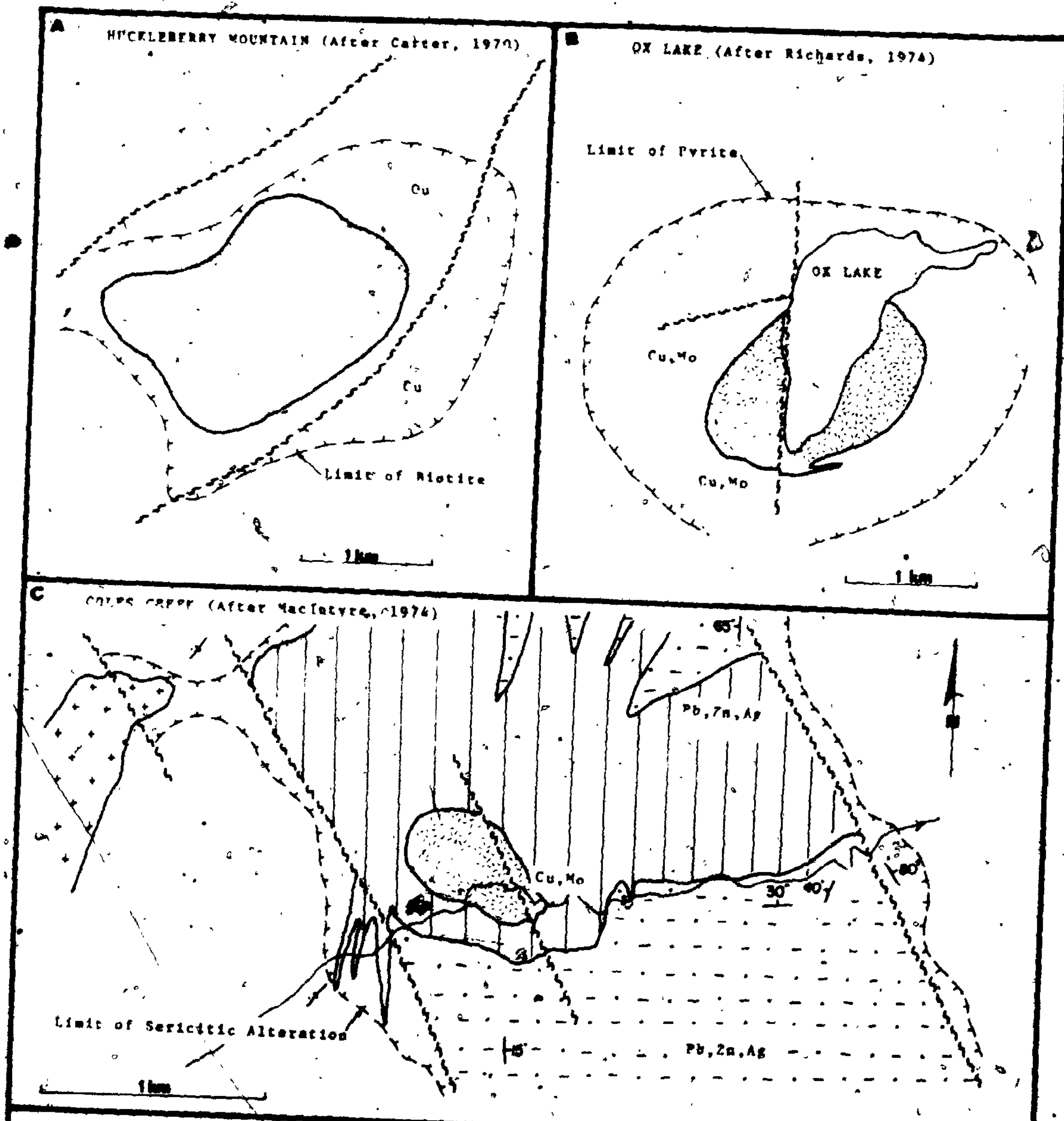


FIGURE 8. GEOLOGY OF HUCKLEBERRY MTN., OX LAKE, AND COLES CREEK PORPHYRY COPPER PROSPECTS

Porphyritic granodiorite — Porphyritic dacite — Quartz diorite

Kasalka Group - Mt.Baptiste Formation — Hazelton Group

30 Bedding attitude — Major fault — Cu - Mineral occurrence

in Figure 6.

Porphyritic Granodiorite

Small, subcircular stocks of porphyritic granodiorite crop out in the vicinity of Ox Lake, Huckleberry Mountain, and Coles Creek (Figure 8). The stocks are exposed at variable stratigraphic positions within the Hazelton Group. The Coles Creek stock also intrudes a sill of porphyritic dacite of the Kasalka Intrusions. Contacts are generally sharp and steeply dipping. Contact metamorphic aureoles of biotite hornfels are well-developed around the Ox Lake and Huckleberry Mountain stocks, but are absent at Coles Creek. The latter is enclosed by an extensive zone of pervasive hydrothermal alteration, (MacIntyre, 1974). In general, the Hazelton Group strata become more steeply dipping adjacent to the stocks, suggesting that doming and uplift accompanied intrusion.

The stocks at Coles Creek, Ox Lake and Huckleberry Mountain are essentially simple, single phase intrusions of light to dark grey porphyritic hornblende-biotite granodiorite. The texture of these rocks ranges from fine-grained sparsely porphyritic, to densely porphyritic with greater than 50 percent euhedral phenocrysts (Plates 7D,F). Coarse-grained, subporphyritic to equigranular textures are characteristic of the core zones of the stocks, particularly at depth. Phenocrysts are mainly 2 to 6 millimeter oscillatory-zoned andesine with subordinate brown biotite, green hornblende and minor anhedral quartz, all set in a microgranular interlocking groundmass of quartz, K-feldspar and minor plagioclase. Apatite and magnetite are important accessory minerals. The average modal composition of each of the stocks is presented in Table 6. A plot of these values (Figure 9) recast to 100 percent, illustrates the relatively small compositional range for these plutons, all of which fall within the granodiorite field as defined by Bateman, et.al. (1963).

Granodiorite and Quartz Diorite

Large, compositionally-zoned stocks of bulk granodiorite to quartz diorite composition, occur in the Tahtsa Lake area. The largest of these is the Sibola Stock, which intrudes Hazelton and Skeena group rocks in the core of the Sibola Range (Figures 4,6). The eastern contact of the stock is sharp and steeply dipping, whereas the western contact appears to dip moderately east. Hazelton Group rocks along the eastern contact are steeply dipping and parallel the trend of the contact. A compositionally similar stock underlies the area south of the northwest tip of Troitsa Lake. This stock is roughly circular in plan and intrudes west dipping Hazelton Group strata (Figure 10c). The contacts of the stock are steeply-dipping and crosscut the bedding. Unlike the Sibola Stock, this intrusion has produced only minor disruption of regional structural trends (Cawthorn, 1974). The quartz diorite stock on Mt. Baptiste, and the quartz diorite dyke at Coles Creek, are texturally and compositionally similar to the border phases of the

TABLE 6. Average modal compositions of the Bulkley Intrusions as determined by point counting.

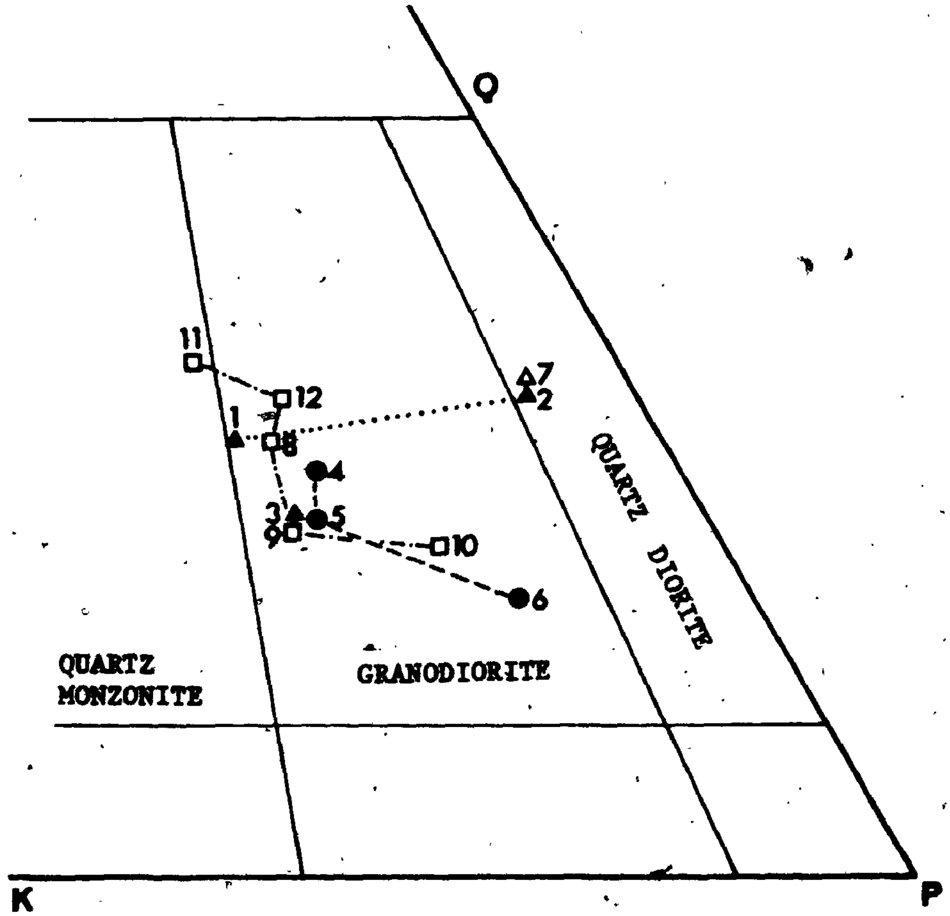
	1	2	3	4	5	6	7	8	9	10	11	12
QZ	21.0	27.5	26.9	24.0	20.9	15.2	26.2	24.0	19.0	20.0	29.8	26.2
KF	20.3	5.8	23.1	19.2	20.3	11.3	4.8	18.8	20.3	15.3	21.3	17.1
PL	46.4	53.2	43.6	47.6	47.7	56.6	48.8	40.8	44.2	57.0	36.9	40.0
BT	3.3	12.5	2.4	3.3	3.3	7.1	16.8	9.0	8.7	3.4	4.8	6.2
HB	7.1	--	2.4	4.7	7.0	6.8	--	1.0	6.0	--	6.2	--
MT	1.9	1.0	0.9	1.2	1.7	2.0	1.2	2.5	1.7	0.9	1.0	1.0
OT	--	--	0.7	--	--	1.0	2.2	3.0	--	4.2	--	9.5

Abbreviations: QZ=quartz; KF=K-feldspar; PL=plagioclase; BT=biotite; HB=hornblende; MT=magnetite; OT=other minerals present.

EXPLANATION OF COLUMN HEADINGS

1. Average of 16 modal analyzes, granodiorite, Sibola Stock. Church, 1971.
2. Average of 5 modal analyzes, camp phase, Sibola Stock. Church, 1971.
3. Sample M-77, granodiorite, Sibola Stock, Whiting Creek.
4. Average of 6 modal analyzes, core zone, Troitsa Stock. Cawthorn, 1973.
5. Average of 8 modal analyzes, intermediate zone, Troitsa Stock. Cawthorn, 1973
6. Average of 5 modal analyzes, contact zone, Troitsa Stock. Cawthorn, 1973.
7. Average of 4 modal analyzes, quartz diorite, Coles Creek. MacIntyre, 1974.
8. Average of 4 modal analyzes, porphyritic granodiorite, Coles Creek. MacIntyre, 1974.
9. Average of 3 modal analyzes, porphyritic granodiorite, Ox Lake. Sutherland Brown, 1969.
10. Sample HB 7 - 430, porphyritic granodiorite, Huckleberry Mountain.
11. Average of 8 modal analyzes, porphyritic quartz monzonite, Bergette. Church, 1971.
12. Sample WC - 8 - 300, porphyritic quartz monzonite, Whiting Creek.

FIGURE 9. Plot of average modal quartz (Q), plagioclase (P), and K-feldspar (K) recalculated to 100 percent for Bulkley Intrusions. Data used is given in Table 6. Classification after Bateman et al., 1963.



1 - 3	Quartz diorite and granodiorite, Sibola Stock
4 - 6	Granodiorite, Troitsa Stock
7	Quartz diorite, Coles Creek
8	Porphyritic granodiorite, Coles Creek
9	Porphyritic granodiorite, Ox Lake
10	Porphyritic granodiorite, Huckleberry Mtn.
11	Porphyritic quartz monzonite, Bergette
12	Porphyritic quartz monzonite, Whiting Crk.

Troitsa and Sibola Stock. Aureoles of biotite hornfels enclose both the granodiorite and quartz diorite intrusions and extend several hundred meters into surrounding wallrocks.

Detailed petrographic study of the Troitsa Lake Stock by Cawthorn (1973) indicates textural and compositional zoning from a coarse-grained biotite-hornblende quartz monzonite in the core to a finer-grained biotite-hornblende granodiorite at the margins. The Sibola Stock is also zoned with a narrow marginal zone of mafic-rich, medium to fine-grained biotite-hornblende quartz diorite, (camp phase of Church 1971) enclosing a core of coarse-grained subporphyritic biotite-hornblende granodiorite (Plate 6B). Similarly, the quartz diorite at Coles Creek has a greater quartz and K-feldspar content toward the center of the dyke where it approaches granodiorite in composition (MacIntyre, 1974). Sampling of the Mt. Baptiste stock was too limited to define any systematic variations in composition.

Equigranular phases of the Bulkley Intrusions in the Tahtsa Lake area vary from dark grey to pinkish-grey in color, according to the relative proportions of biotite and K-feldspar present. The rocks are characterized by an hypidiomorphic granular to subporphyritic texture consisting of closely packed 2 to 5 millimeter subhedral to euhedral oscillatory-zoned oligoclase and andesine phenocrysts (Plate 6E), many of which appear to be partly resorbed. Smaller subhedral biotite and hornblende grains, and anhedral quartz, occupy the spaces between the plagioclase

Plate 7

A Porphyritic dacite of the Kasalka Intrusions, Coles Creek. Note the rounded quartz (qz) eyes and subhedral plagioclase phenocrysts set in an aphanitic groundmass of quartz, K-feldspar and plagioclase.

B Photomicrograph of porphyritic rhyodacite from the north shore of Troitsa Lake. Embayed and rounded quartz (qz), broken plagioclase (pl) and euhedral K-feldspar phenocrysts are set in a microgranular groundmass of quartz and K-feldspar. X-nicols, sample D-188.

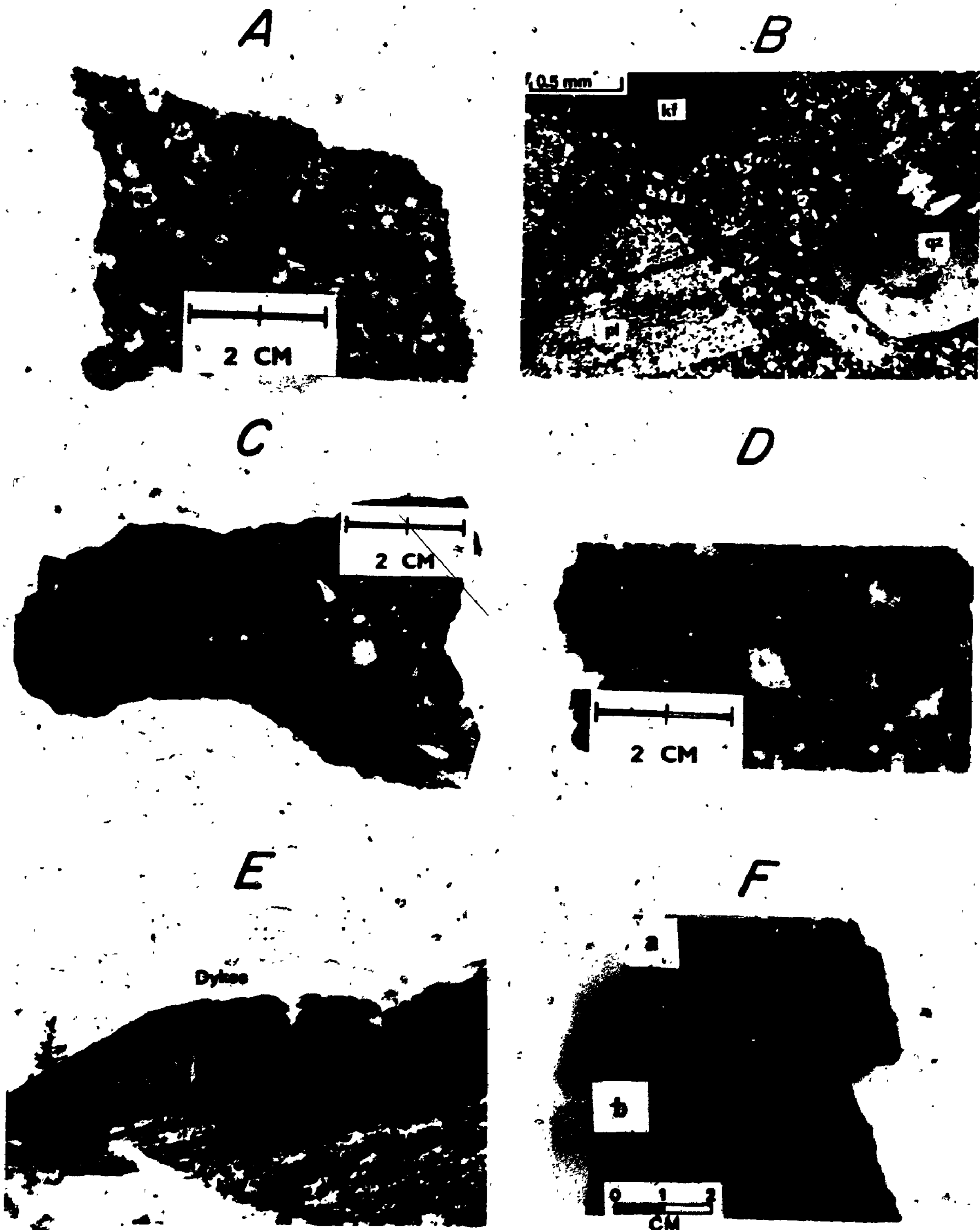
C Pebble dyke with angular clasts of porphyritic dacite set in an aphanitic dark grey siliceous matrix. Sample from Coles Creek.

D Typical sample of porphyritic hornblende-biotite granodiorite of the Bulkley Intrusions. Note crowded porphyritic texture. Sample from the core of the Coles Creek stock.

E Vertical northwest-trending dykes cutting Hazelton Group strata near the Emerald Glacier Mine. View looking northwest from the access road.

F Samples of porphyritic granodiorite from the Ox Lake (a) and Huckleberry Mountain (b) porphyry copper occurrences.

PLATE 7



phenocrysts. K-feldspar and fine-grained granular quartz are interstitial to the larger grains. Magnetite is a ubiquitous accessory mineral along with apatite and sphene.

The modal composition of samples from the Sibola and Troitsa stocks have been determined by Church (1971) and Cawthorn (1973), respectively. The average values for various zones of the intrusions are given in Table 6 and clearly illustrate the progressive increase in modal K-feldspar and quartz toward the core zones. The relative proportions of K-feldspar, quartz and plagioclase recast to 100 percent for the main phases of the Sibola and Troitsa stocks, are very close to those determined for porphyritic granodiorite at Ox Lake, Coles Creek and Huckleberry Mountain (Table 6, Figure 9). The average modal composition of the quartz diorite border phase of the Sibola stock is nearly identical to that of the Coles Creek quartz diorite (Figure 9).

Rhyodacitic Intrusions

Small, irregular dykes and sills of rhyodacitic composition intrude both the Sibola and Troitsa stocks (Figure 10). The contacts are sharp and lack chilled margins. Inclusions of host rocks are common, particularly adjacent to the contacts. At the Bergette porphyry copper prospect, the rhyodacite grades into breccia pipes and dykes. A similar breccia pipe is located along the south contact of the quartz diorite at Coles Creek.

Rhyodacitic intrusions within the Sibola and Troitsa stocks are white siliceous rocks which are locally flow-

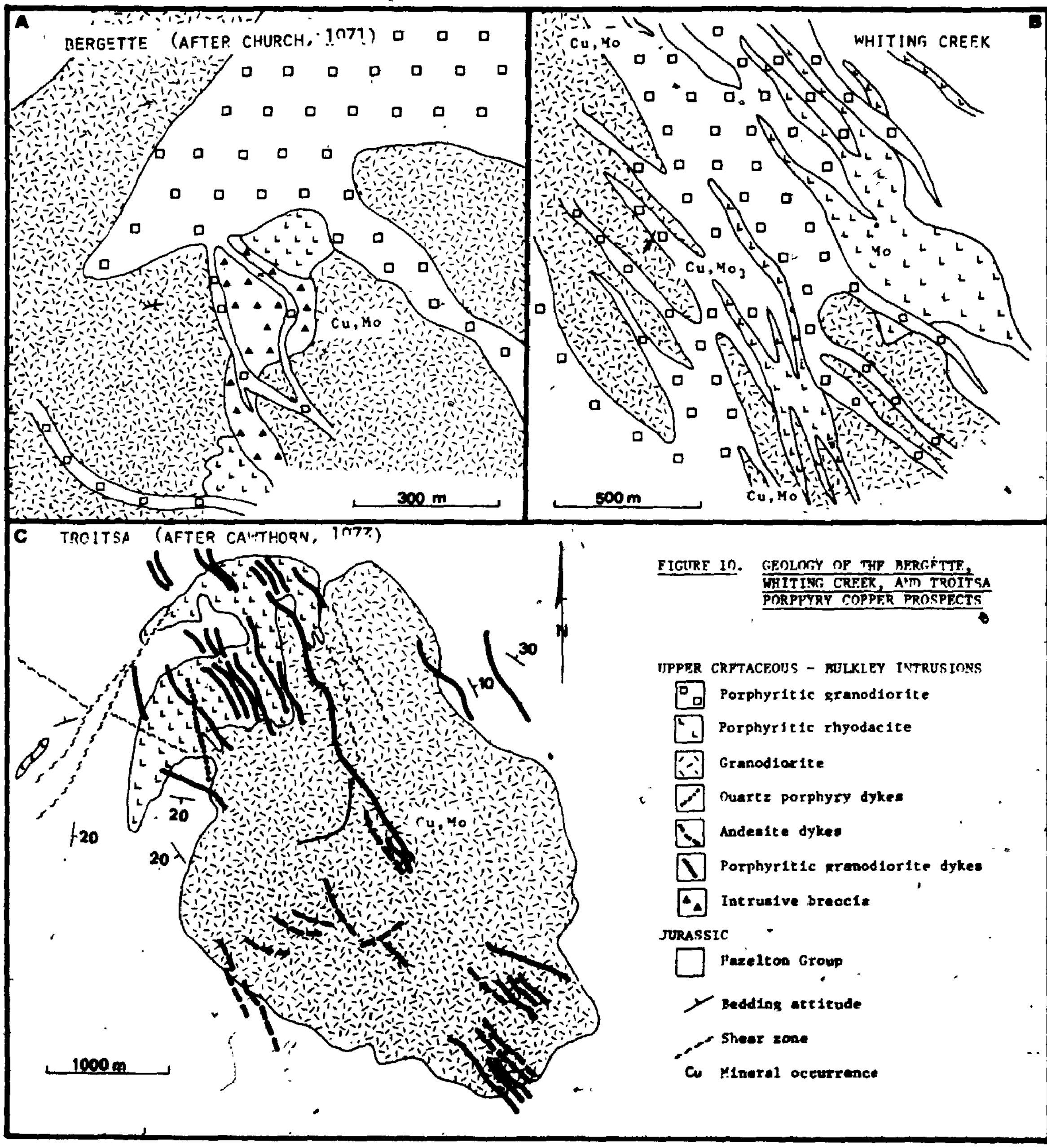


FIGURE 10. GEOLOGY OF THE BERGETTE, WHITING CREEK, AND TROITSA PORPHYRY COPPER PROSPECTS

banded. These rocks characteristically contain 10 to 15 percent subhedral quartz eyes and 1 to 2 percent pyrite cubes set in a microgranular intergrowth of quartz with subordinate K-feldspar and muscovite and very minor albite. Phenocrysts, or outlines of phenocrysts, of plagioclase, biotite and hornblende, are conspicuously absent. The muscovite appears to be a primary component of these rocks. Associated breccias contain angular rhyolitic clasts set in a microcrystalline quartz-muscovite matrix. Intrusive rocks of similar texture and composition have been called quartz porphyry, quartz porphyry rhyolite and rhyolite in the past. However, the term rhyodacite is used in this study because it is consistent with the aphanitic texture and true chemical composition of these rocks.

Porphyritic Quartz Monzonite

Northwest-trending dyke swarms of porphyritic quartz monzonite, which locally coalesce to form irregular elongate stocks, intrude the Sibola and Troitsa stocks (Figure 10). The dykes rarely have chilled margins and the contacts with wallrocks are usually sharp. By contrast, dykes which extend outside of the stocks typically have fine-grained mafic-rich border zones and coarse-grained porphyritic cores.

The porphyritic quartz monzonite intrusions at the Bergette and Whiting Creek prospects are pinkish grey to buff-colored rocks with a well-developed coarse-grained porphyritic texture (Plate 8A). The quartz monzonite contains a greater percentage of anhedral quartz phenocrysts and groundmass K-feldspar than the porphyritic granodiorite at Ox Lake, Coles Creek and Huckleberry Mountain. The average modal composition of the Bergette and Whiting Creek intrusions is given in Table 6. The quartz-K-feldspar-plagioclase ratio of these rocks straddles the quartz monzonite-granodiorite boundary in Figure 9.

Mt. Bolom Intrusions

The Mt. Bolom Stock is in the southwest corner of the map area, west of Troitsa Lake. It is roughly circular in plan and underlies an area of approximately 54 square kilometers, forming the core of Mt. Bolom and of ridges to the north (Figure 6). The stock intrudes metamorphic rocks of the Coast Plutonic Complex on the west and the Hazelton, Skeena and Kasalka Groups on the east. The contacts are sharp and discordant, with contact metamorphism restricted to rocks immediately adjacent to the stock. The Kasalka Group strata along the north contact have been isoclinally-folded, and the Hazelton Group strata have been tilted to a vertical position parallel to the south contact. Dykes of similar composition and texture to the Mt. Bolom Stock are common in the Kasalka range, and are believed to be related to the stock (Figure 23 in pocket).

Only the eastern half of the Mt. Bolom stock was mapped during this study. In this area, the stock is essentially a pink porphyritic biotite-hornblende granophyre, which is texturally-zoned from a sparsely porphyritic, fine-

Plate 8

A A typical sample of porphyritic quartz monzonite from the Whiting Creek prospect. Note the euhedral nature of the phenocrysts and the presence of quartz "eyes" (qz).

B Two samples of the Berg porphyritic quartz monzonite. Note the large K-feldspar (kf) and quartz (qz) phenocrysts.

C Photomicrograph of a typical sample of porphyritic granophyre from the Mt. Bolom Stock. Note the granophyric texture of the groundmass and the subhedral plagioclase phenocrysts (dark to light grey). X-nicols, sample M-194.

D Fine (a) and medium (b) grained samples of the Berg quartz diorite.

E Photomicrograph of Berg quartz diorite with alignment of tabular plagioclase (pl) and hornblende (hb) phenocrysts and interstitial quartz (qz) and K-feldspar (kf). X-nicols, sample M-155.

quartz as fracture fillings in a gossanous zone roughly centered on a northwest-trending porphyritic quartz monzonite dyke swarm, and an irregular stock (Church, 1971). The sulphide-bearing fractures typically have sericitized borders. Seams of pyrite and chalcopyrite up to several centimeters thick are also common. Sulphide concentration also occurs within a small breccia pipe. Fractures within this breccia are healed with molybdenite, pyrite, gypsum and minor flourite, and vugs are lined with calcite, pyrite, chalcopyrite, magnetite, epidote, biotite and zeolites.

The Whiting Creek prospect is also marked by an extensive gossan zone centered on a series of northwest-trending porphyritic quartz monzonite dykes. The predominant sulphide mineral is pyrite, which occurs as fracture fillings within the Sibola Stock and hornfelsed rocks northeast of the stock. Fractures locally contain chalcopyrite and typically have sericite-rich alteration envelopes (Plate 9B). Molybdenite occurs as banded quartz veins (Plate 9A), and disseminations within the porphyritic rhyodacite. The mode of occurrence of this mineral concentration is very similar to that observed at the Hudsons Bay Mountain deposit near Smithers, British Columbia (Jonson, et.al., 1968)

4.5 Structural Features

Structural cross sections of the Tahtsa Lake area are given in Figure 11, and major tectonic elements are shown in Figure 12 and Figure 23A (in pocket). In grained border phase, to a coarser-grained, more porphyritic core. The rock contains euhedral unzoned oligoclase, plus fewer subhedral biotite and hornblende phenocrysts, set in a groundmass of interlocking laths of plagioclase, with interstitial granophyric intergrowths of K-feldspar and quartz (Plate 8C). The groundmass plagioclase is typically altered to clay and secondary albite. A characteristic feature of the granophyre is the presence of clusters of hornblende, biotite and plagioclase crystals. Dark grey to black wallrock inclusions are also common. Similar features are found in dykes peripheral to the Mt. Bolom stock. However, in contrast to the stock, these dykes contain more biotite and little or no hornblende. The Mt. Bolom stock differs from the Bulkley and Kasalka Intrusions by having significantly more K-feldspar and less quartz.

Dyke Swarms

Northwest-trending dyke swarms of basaltic to rhyolitic composition are common throughout the map-area (Figure 6) and intrude all rocks of earliest Upper Cretaceous age, and older (plate 7E). Four major groups of dykes are recognized and these are: (1) rhyodacite, (2) andesite, (3) basalt and (4) lamprophyre.

Rhyodacite

Rhyodacite dykes trend parallel to the northwest shore of Troitsa Lake, where they crop out as distinctive white cliffs. Similar dykes crop out on Mt. Baptiste and on the south and north shores of Tahtsa Lake. Dyke contacts are generally sharp and steeply-dipping.

Rhyodacite dykes are white to cream-colored siliceous rocks which are exceptionally resistant to weathering. Porphyritic phases contain quartz, plagioclase and K-feldspar phenocrysts which are set in a micro-crystalline groundmass of quartz and muscovite (Plate 7B). Plagioclase phenocrysts are invariably pseudomorphed by fine-grained aggregates of clay, sericite and albite. Pyrite cubes are also common in these rocks.

Andesite

Hornblende-biotite andesite dykes cut the granodiorite, rhyodacite and porphyritic quartz monzonite of the Troitsa stock (Figure 10 C). These dykes are usually unaltered relative to their host rocks suggesting they are mainly post-mineral in age (Cawthorn, 1973). Similar dykes intrude the quartz diorite at Coles Creek. These andesitic dykes contain biotite and lack augite, features that distinguish them from andesitic dykes of the Kasalka Intrusions.

Basalt

Andesite dykes are cut by basalt and lamprophyre dykes within the Troitsa stock and at Coles Creek. Basalt dykes are also very common in the Kasalka Range where they occur as a northwest-trending, vertical dyke swarm cutting rocks of the Kasalka Group. Northeast and easterly trends are also common. Individual dykes are rarely greater than 10 meters in width.

The basaltic dykes are very susceptible to weathering and in most cases, original petrographic features have been destroyed. The most characteristic feature of these rocks is the presence of calcite-filled amygdules and numerous pipe-like vesicles.

Lamprophyre

Lamprophyre dykes are relatively rare in the Tahtsa Lake area, and generally occur as isolated dykes rather than as swarms. Lamprophyre dykes cut the andesite dykes within the Troitsa stock, the rhyodacite dyke on the south slope of Mt. Baptiste, and the Mt. Bolom stock southeast of Laventie Mountain. The lamprophyre is a dark grey rock containing up to 60 percent biotite and chlorite phenocrysts in an aphanitic plagioclase-rich groundmass. Lamprophyres of this mineralogy are classified as Kersantites by Williams, et.al., (1954).

Potassium Argon Dating of Plutonic Rocks

The British Columbia Department of Mines and Petroleum Resources, using the geochronology laboratory at the University of British Columbia, has determined K-Ar isotopic ages for most of the Bulkley Intrusions present in the Tahtsa Lake area (Carter, 1974; Appendix D). Of these, the porphyritic granodiorite stocks at Ox Lake, Coles Creek and Huckleberry Mountain are the oldest at 83.4 $\pm$ 3.2, 83.8 $\pm$ 2.8 and 82.0 $\pm$ 3.0 million years, respectively. The Troitsa stock and the Bergette porphyritic quartz monzonite have slightly younger ages of 75.7 ± 2.3 and 76.7 ± 2.5 million years, respectively. Similar ages are inferred for the Whiting Creek quartz monzonite. Unfortunately, the only K-Ar isotopic age available for the Kasalka Intrusions is for a latite-andesite dyke exposed on the north slope of Swing Peak. The apparent age, as determined by Teledyne Isotopes for a whole rock sample, is 104 ± 8 million years (Appendix D).

4.4 Porphyry Copper Occurrences

Zones of copper and molybdenum concentration of the porphyry copper type are spatially associated with porphyritic granodiorite and quartz monzonite of the Bulkley Intrusions. These can be subdivided into two groups on the basis of age and mode of occurrence. These are (1) occurrences associated with small subcircular stocks of porphyritic granodiorite, such as at Huckleberry Mountain, Ox Lake and Coles Creek (82-83 m.y.), and (2) occurrences associated with porphyritic quartz monzonite dykes within larger granodiorite stocks such as the Troitsa, Bergette and Whiting Creek prospects (c.a. 76-78 m.y.). The most important features of these deposits are summarized in Table 7.

The most economically significant occurrence of Upper Cretaceous age in the Tahtsa Lake area is at Huckleberry Mountain. Here, biotite hornfels immediately east of the porphyritic granodiorite stock, contain ore grade concentrations of copper, primarily as closely-spaced hair-line fractures coated with chalcopyrite and minor quartz

TABLE 7. SUMMARY OF THE MAIN FEATURES OF UPPER CRETACEOUS PORPHYRY COPPER DEPOSITS.

Deposit Name	Igneous Host Rock	K-Ar Age	Mineralized Rocks	Ore Minerals	Mode of Occurrence
COLES CREEK	Porphyritic Granodiorite Stock	83.8 $\pm$ 2.8	Porphyritic granodiorite	Chalcopyrite, minor bornite, molybdenite	Quartz veinlet stockwork and disseminated
OX LAKE	Porphyritic Granodiorite Stock	83.4 $\pm$ 3.2	Mainly within biotite hornfels enclosing stock	Chalcopyrite, molybdenite, minor bornite	As fracture fillings and in qz veinlets
HUCKLEBERRY MOUNTAIN	Porphyritic Granodiorite Stock	82.0 $\pm$ 3.0	Same as above	Mainly chalcopyrite	Hairline fracture coating, qz veinlets and disseminated
BERGETTE	Porphyritic Quartz Monzonite Stock &	76.7 $\pm$ 2.5	Sibola Stock and porphyritic intrusions. Mo in rhyodacite.	Chalcopyrite, minor molybdenite	Mainly in widely spaced qz healed fractures and in matrix of breccia
WHITING CREEK	Porphyritic Quartz Monzonite Dykes	??	Sibola Stock and biotite hornfels. Mo in rhyodacite	Chalcopyrite, molybdenite	As fracture filling and in qz veinlet stockwork; disseminated
TROITSA	Porphyritic Quartz Monzonite Dykes	75.7 $\pm$ 2.3	Mainly within and adjacent dykes in Troitsa Stock	Chalcopyrite, molybdenite, bornite	In qz healed fractures surrounding dykes

and magnetite (Figure 8A). Chalcopyrite also occurs in quartz veinlets, with trace amounts of molybdenite and K-feldspar. Metamorphic biotite is altered to sericite and plagioclase to K-feldspar adjacent to these veinlets (Plate 9B). Chalcopyrite also occurs as veinlets and disseminations within the stock, but is generally not sufficiently concentrated to make ore grade material. Pyrite predominates peripheral to the stock and extends up to 600 meters beyond the ore zone.

The Ox Lake occurrence is very similar to Huckleberry Mountain, the main differences being a greater amount of molybdenite and more extensive hydrothermal alteration. Here, the best grade material is located west of the stock in brecciated and unbrecciated biotite hornfels. As at Huckleberry Mountain, chalcopyrite and molybdenite occur as fracture coatings and quartz veinlet stockworks. Molybdenite concentration is greatest within felsic dykes near the contact of the stock. Veining within the ore zone is complex with at least four major stages being recognized. According to Richards (1974) the earliest of these contain K-feldspar and biotite and are cut by successive stages of chlorite-pyrite-chalcopyrite, quartz-molybdenite and calcite-gypsum-sphalerite-bearing veins and veinlets. Plagioclase is altered to sericite, clay and calcite, and biotite is altered to sericite and chlorite within the ore zone. Alteration intensity decreases away from the stock with successive zones of epidote and actinolite alteration of mafic minerals restricted to envelopes on sulphide veinlets. To the north and east of the stock, an outer zone of pervasive K-feldspar alteration of plagioclase is separated from the intrusion by a zone of albite and chlorite alteration of plagioclase and biotite. Pyrite, both as disseminations and in veinlets occurs in a halo, up to 500 meters wide, enclosing the stock (Figure 8B).

Minor concentrations of copper and molybdenum, primarily as chalcopyrite and molybdenite in quartz veinlet stockworks (Plate E) occur within the outer margins of the porphyritic granodiorite stock at Coles Creek (Figure 8C). In this area, plagioclase is extensively altered to secondary K-feldspar and the groundmass contains abundant fine-grained biotite. Porphyritic dacite enclosing the stock is pervasively and completely altered to a fine-grained assemblage of sericite-quartz and pyrite. A downfaulted block of pyroclastic rocks of the Mt. Baptiste Formation south and east of the stock is also pervasively altered, primarily to sericite, clay, carbonate and microcrystalline silica. These rocks also contain abundant disseminated pyrite, with minor amounts of galena and sphalerite. By contrast, rocks of the Hazelton Group west of the stock are hornfelsed and cut by widely-spaced pyrite veinlets with sericitic alteration envelopes. A small breccia pipe is located along the south contact of the quartz diorite at Coles Creek, approximately 1500 meters upstream from the porphyritic granodiorite stock. This breccia contains angular clasts of rhyolitic rock cemented in a chalcopyrite, pyrite, molybdenite and magnetite rich matrix. Galena and sphalerite crystals line and fill vugs within the breccia.

Porphyry copper mineral concentration is also associated with porphyritic quartz monzonite dykes within the Sibola and Troitsa stocks (Figure 10). In general, hydrothermal alteration and sulphide mineral concentration is centered on individual dykes and decreases outward into the host rocks. This is best shown at the Troitsa prospect where sulphides occur in intensely-fractured rock adjacent to northwest-trending porphyritic quartz monzonite dykes cutting the core of the Troitsa stock. Alteration and sulphide zoning is typical of porphyry copper deposits, with chalcopyrite, molybdenite and bornite occurring as veins and fracture coatings, enclosed by biotite and orthoclase enriched alteration envelopes, mainly within the dykes (Cawthorn, 1973). Outward from the dykes, pyrite predominates, primarily as fracture fillings enclosed by sericitized alteration envelopes. This grades into an outer zone of propylitic alteration characterized by replacement of mafic minerals by chlorite and epidote and albitization of plagioclase.

Two major porphyry copper prospects occur within the Sibola Stock (Figure 10A,B). At the Bergette prospect, pyrite, chalcopyrite and minor molybdenite occur with

Plate 9

A Molybdenite-bearing quartz veins in porphyritic rhyodacite at the Whiting Creek prospect. Note banded nature of the mineral concentration in sample (b).

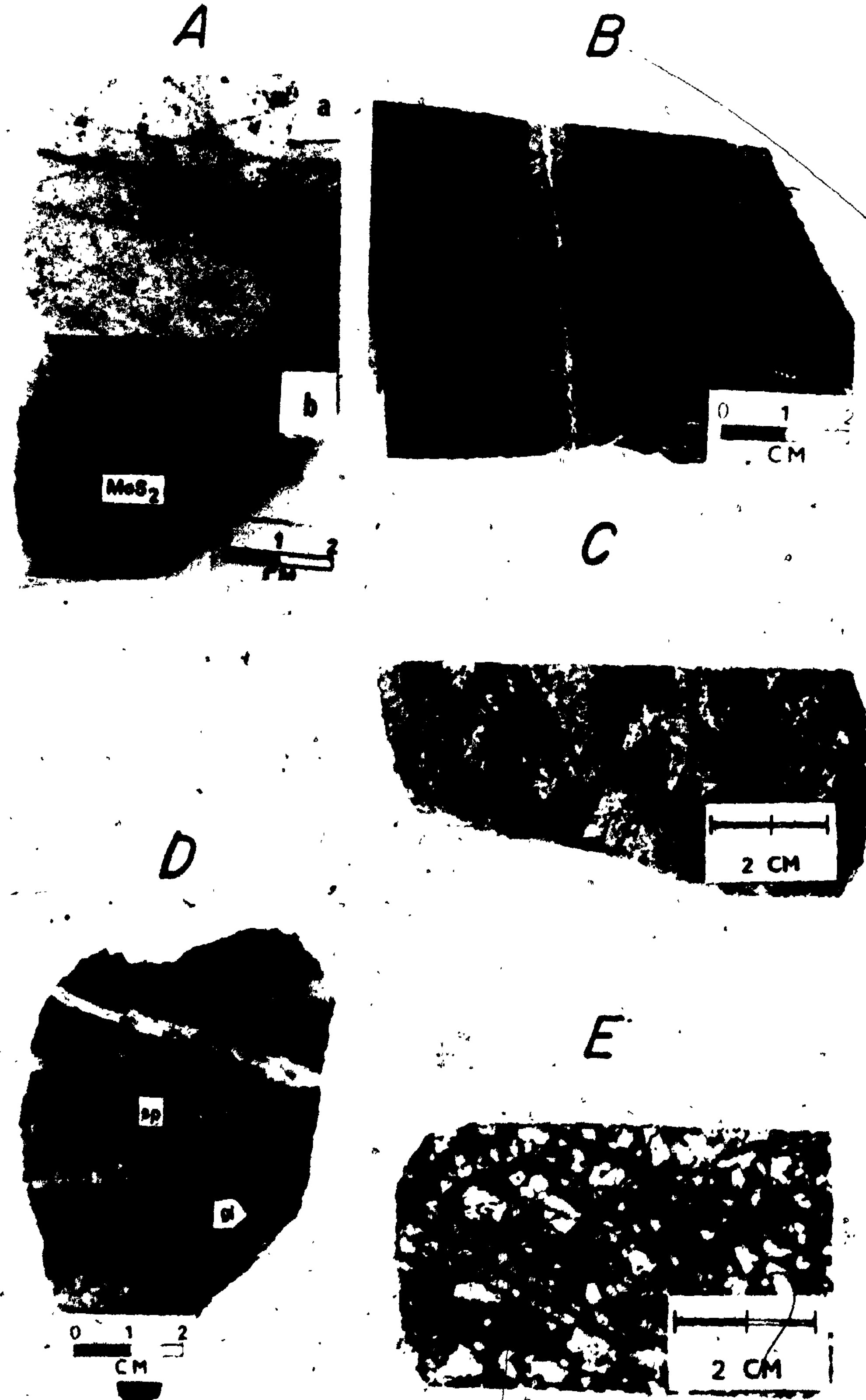
B A typical sample of biotite hornfels cut by a network of pyrite veinlets with sericitic alteration envelopes. Sample from Whiting Creek.

C Intrusive rhyodacite breccia from the Coles Creek prospect. The matrix contains chalcopyrite, galena, sphalerite and pyrite.

D A sample of massive sphalerite (sp) and galena (gl) from the Emerald Glacier mine. Note the crude layering of sulphides and the crosscutting carbonate vein.

E A quartz-veinlet stockwork cutting biotite-orthoclase altered porphyritic granodiorite from the Coles Creek Prospect. The veinlets contain pyrite and chalcopyrite.

PLATE 9



quartz as fracture fillings in a gossanous zone roughly centered on a northwest-trending porphyritic quartz monzonite dyke swarm, and an irregular stock (Church, 1971). The sulphide-bearing fractures typically have sericitized borders. Seams of pyrite and chalcopyrite up to several centimeters thick are also common. Sulphide concentration also occurs within a small breccia pipe. Fractures within this breccia are healed with molybdenite, pyrite, gypsum and minor flourite, and vugs are lined with calcite, pyrite, chalcopyrite, magnetite, epidote, biotite and zeolites.

The Whiting Creek prospect is also marked by an extensive gossan zone centered on a series of northwest-trending porphyritic quartz monzonite dykes. The predominant sulphide mineral is pyrite, which occurs as fracture fillings within the Sibola Stock and hornfelsed rocks northeast of the stock. Fractures locally contain chalcopyrite and typically have sericite-rich alteration envelopes (Plate 9B). Molybdenite occurs as banded quartz veins (Plate 9A), and disseminations within the porphyritic rhyodacite. The mode of occurrence of this mineral concentration is very similar to that observed at the Hudsons Bay Mountain deposit near Smithers, British Columbia (Jonson, et.al., 1968)

4.5 Structural Features

Structural cross sections of the Tahtsa Lake area are given in Figure 11, and major tectonic elements are shown in Figure 12 and Figure 23A (in pocket). In

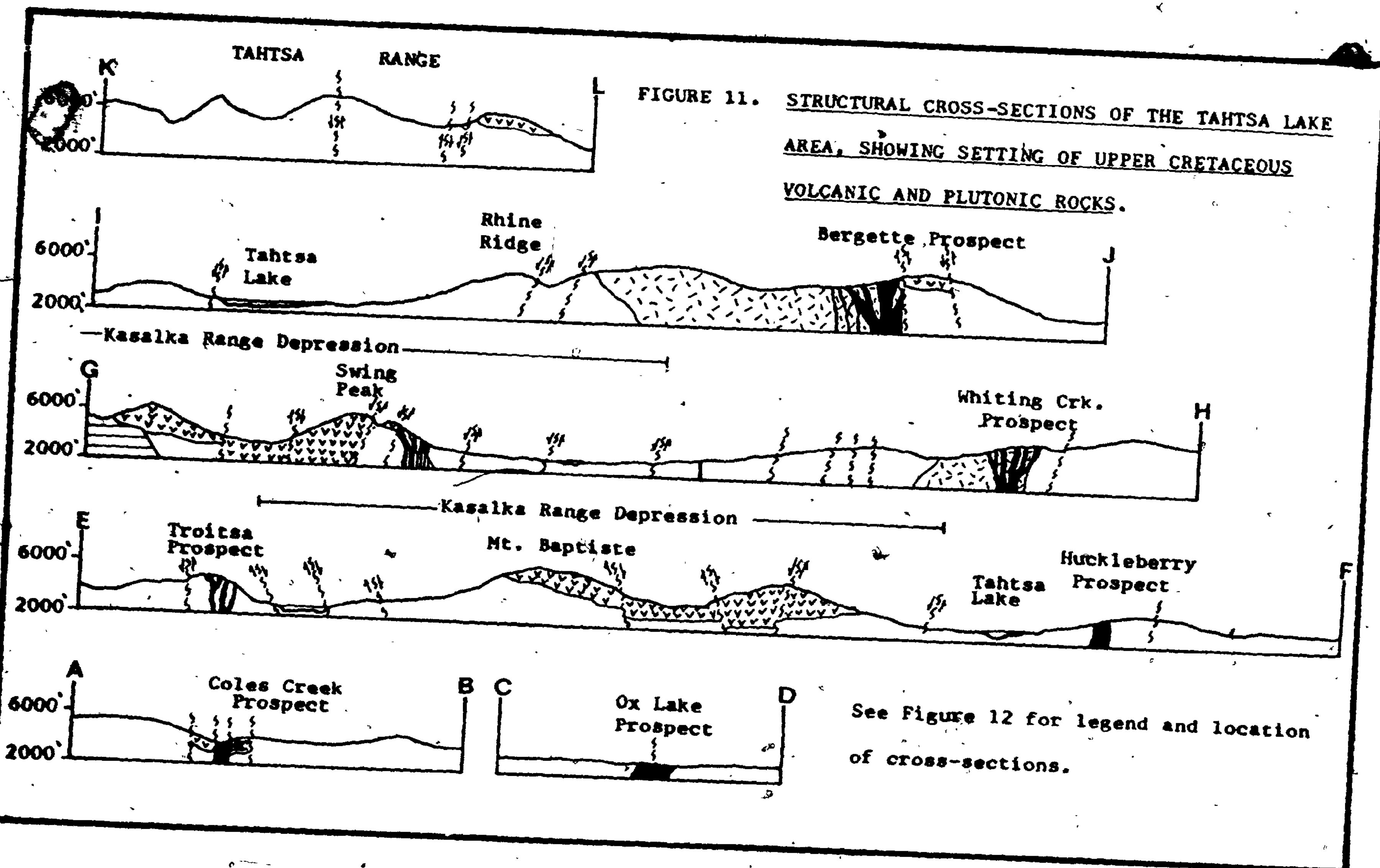


FIGURE 11. STRUCTURAL CROSS-SECTIONS OF THE TAHTSA LAKE AREA, SHOWING SETTING OF UPPER CRETACEOUS VOLCANIC AND PLUTONIC ROCKS.

See Figure 12 for legend and location of cross-sections.

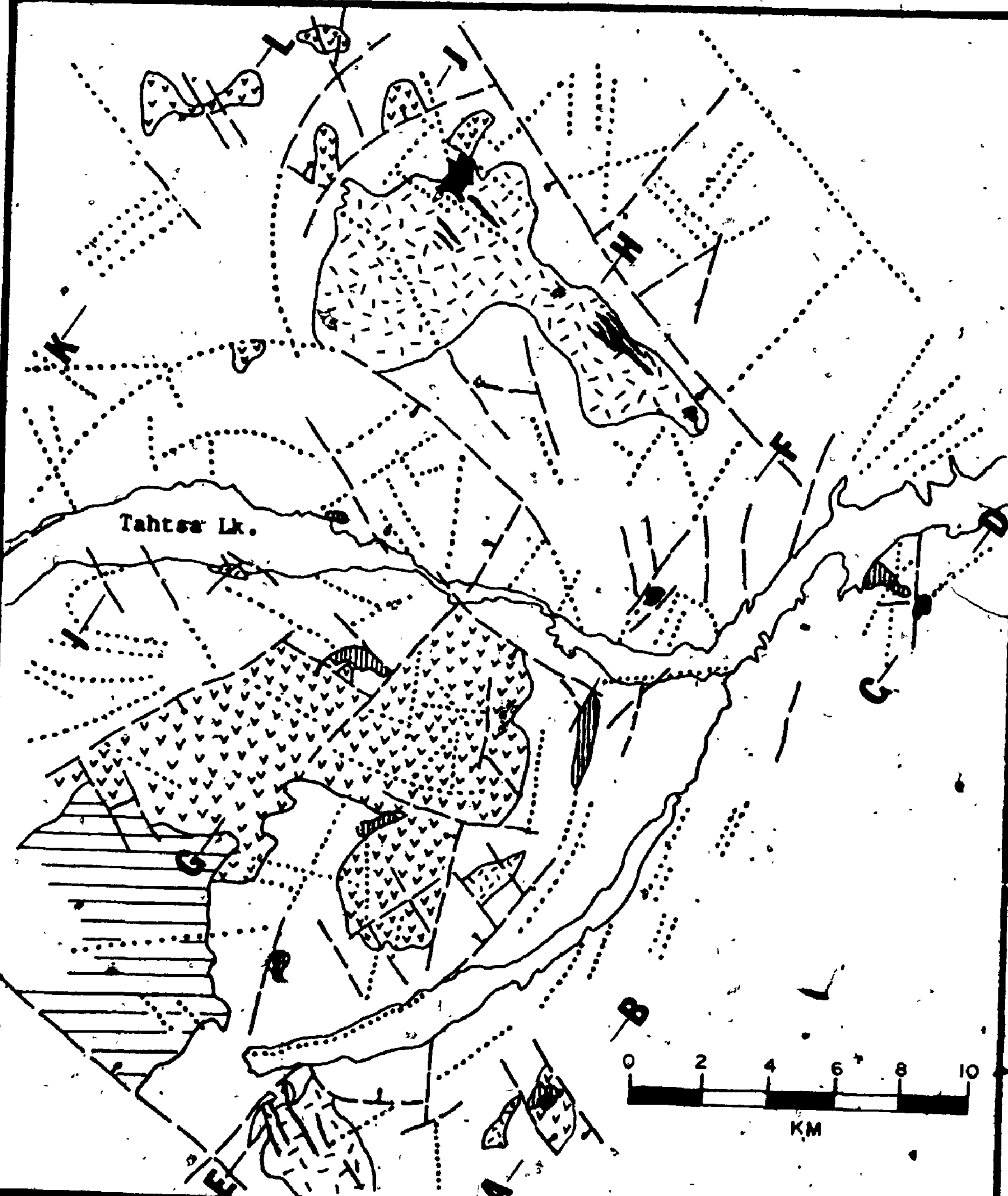


FIGURE 12. DISTRIBUTION OF UPPER CRETACEOUS VOLCANIC AND PLUTONIC ROCKS WITH RESPECT TO MAJOR TECTONIC ELEMENTS IN THE TAHTSA LAKE AREA.

MT. BOLOM INTRUSIONS

KASALKA INTRUSIONS

BULKLEY INT. porphyritic / equigranular

KASALKA GROUP

Major fault - ball on downthrown block

Airphoto lineat

quartz, muscovite and albite. Such rocks could form in a manner similar to that proposed for peraluminous volcanic rocks of the Mt. Baptiste and Bergette Formation. That is, during the final stages of crystallization of the Troitsa and Sibola Stocks, the core was probably occupied by a crystal mush of quartz monzonite composition (Figure 19b). A sudden decrease in confining pressure at this time, might have resulted in liberation of an aqueous phase which slowly accumulated in the top of the magma reservoir. As vapor pressure increased, alkalies would be preferentially partitioned into this aqueous phase, thus leaving a residual melt of peraluminous composition (Burnham, 1967). Subsequent rupturing of the magma chamber would result in rapid injection of the residual melt and volatile-rich aqueous phase towards the surface where it would crystallize rapidly to form dykes and sills of rhyodacite. The zones of brecciation and hydrothermal alteration associated with these intrusions probably represent escape channels for the gas-charged fluids (Norton and Cathles, 1973). Rifting continued after crystallization of the rhyodacite, with concommitant injection of partly crystallized magma of quartz monzonite composition along northwest-trending faults.

The mode of emplacement of the Bulkley Intrusions is difficult to determine. For the most part rocks adjacent to the intrusions have steep dips and there is some evidence for forceful intrusion and doming. This is particularly general, Upper Cretaceous volcanic rocks are much less deformed than the rocks they overlie, generally being flat-lying to gently-dipping. These rocks are cut by numerous northwest and northeast-trending faults, particularly in the Kasalka Range. Offset along these faults is variable, the greatest occurring along faults on the north slope of Swing Peak ridge and Mt. Baptiste. Fault blocks south of Swing Peak ridge have been downthrown by as much as 1000 meters. These movements account for the great thickness of Upper Cretaceous volcanic rocks preserved in the Kasalka Range, which appears to be a major structural depression. Wall rocks bounding faults within, and peripheral to the Kasalka Range, are typically brecciated and pervasively altered to sericite, quartz and pyrite.

The Bulkley intrusions and associated porphyry copper occurrences are located peripheral to the Kasalka Range depression (Figures 11,12). Late porphyritic dykes and fractures within these intrusions have a predominant northwest trend consistent with those observed in older and younger rocks (Figure 13). Subordinate northeast trends are also present although northeast-trending dykes are relatively rare compared to northeast-trending fractures (Figure 13). Northwest-trending shear zones cut the Troitsa and Coles Creek stocks. At Coles Creek, intense sericitic alteration is centered on these shears and has been superimposed on earlier alteration assemblages (MacIntyre, 1974). Steeply dipping shear zones also occur

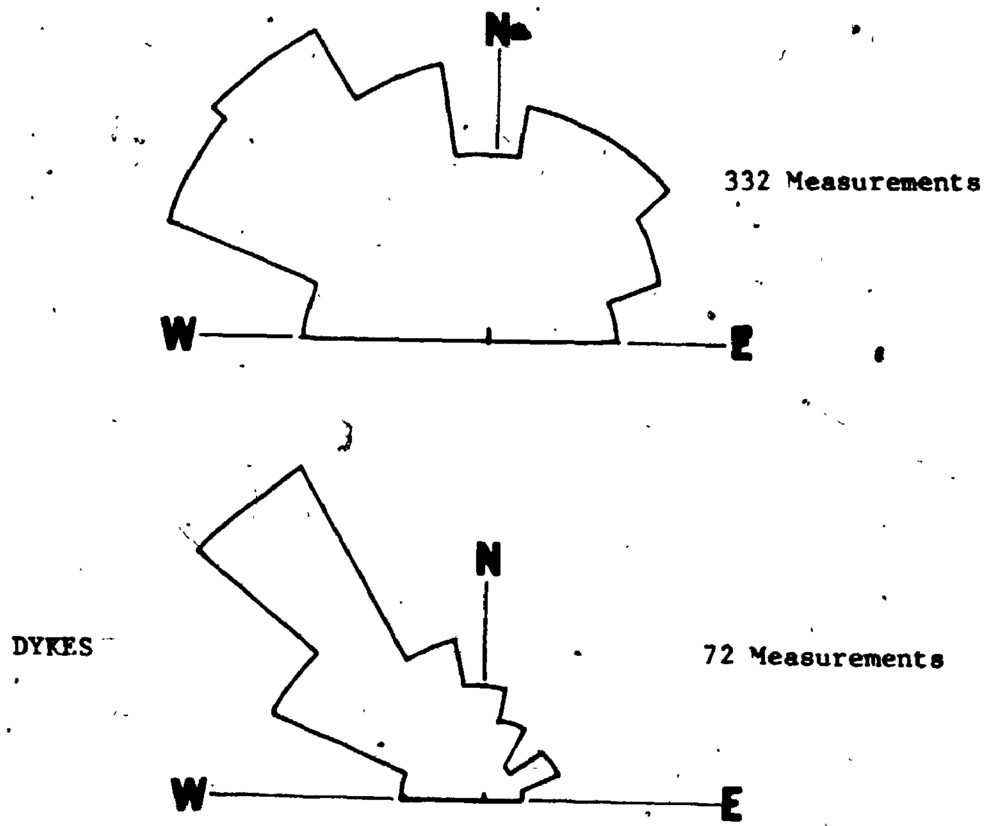


FIGURE 13. Frequency diagram for trends of joints and dykes, Tahtsa Lake Area.

within, and adjacent to, the Ox Lake and Huckleberry Mountain stocks, and these have north and northeasterly trends, respectively. Similarly, porphyritic quartz monzonite dykes within the Sibola Stock are northwest-trending, and are cut and locally offset by northeast-trending shears.

4.6 Chemical Composition

The whole rock chemical composition of representative hand specimens of Upper Cretaceous volcanic and plutonic rocks from the Tahtsa Lake area were determined by X-ray fluorescence spectroscopy. Analytical results and calculated CIPW molecular norms are given in Tables 8, 9, 10, and 11, and sample locations are shown on Figure 14. Analytical procedures and discussion of results are summarized in Appendix B.

The major oxide contents of analyzed Upper Cretaceous rocks are plotted on a Harker silica-variation diagram (Figure 15). The data points cover a range of SiO_2 values from 58 to 80 percent, and define normal trends with Al, Fe, Mg, Ca, and Ti decreasing, K increasing and Na remaining approximately constant for increasing SiO_2 content. The scatter of data points about the trend lines is typical for such plots (e.g. Larsen 1948, Bateman and Dodge, 1970) and reflects varying degrees of alteration and differentiation for the different rock units sampled. The trend lines for Upper Cretaceous rocks in the Tahtsa Lake area parallel those determined by Williams (1942) for volcanic rocks of the Crater Lake area, Cascades volcanic

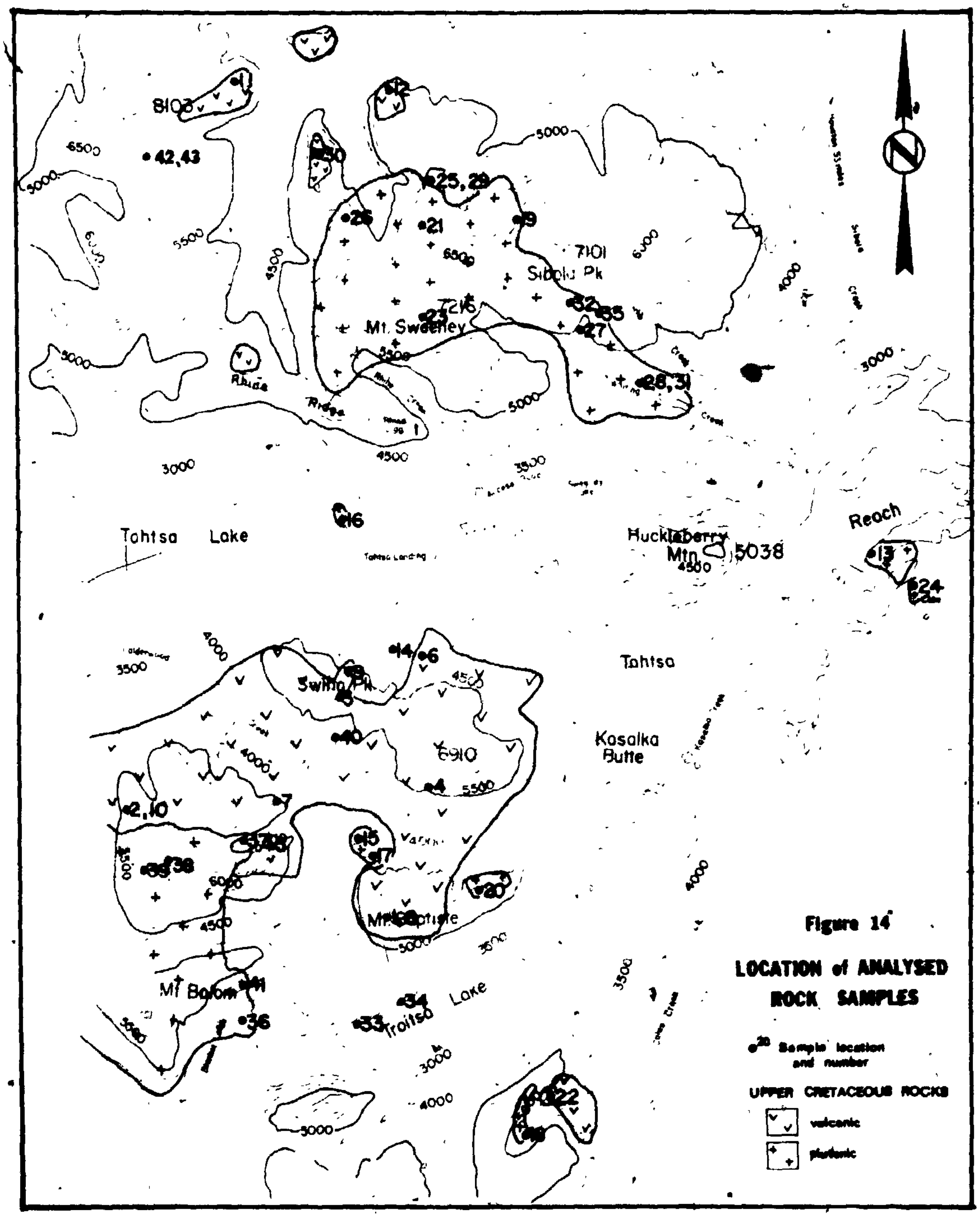


Figure 14

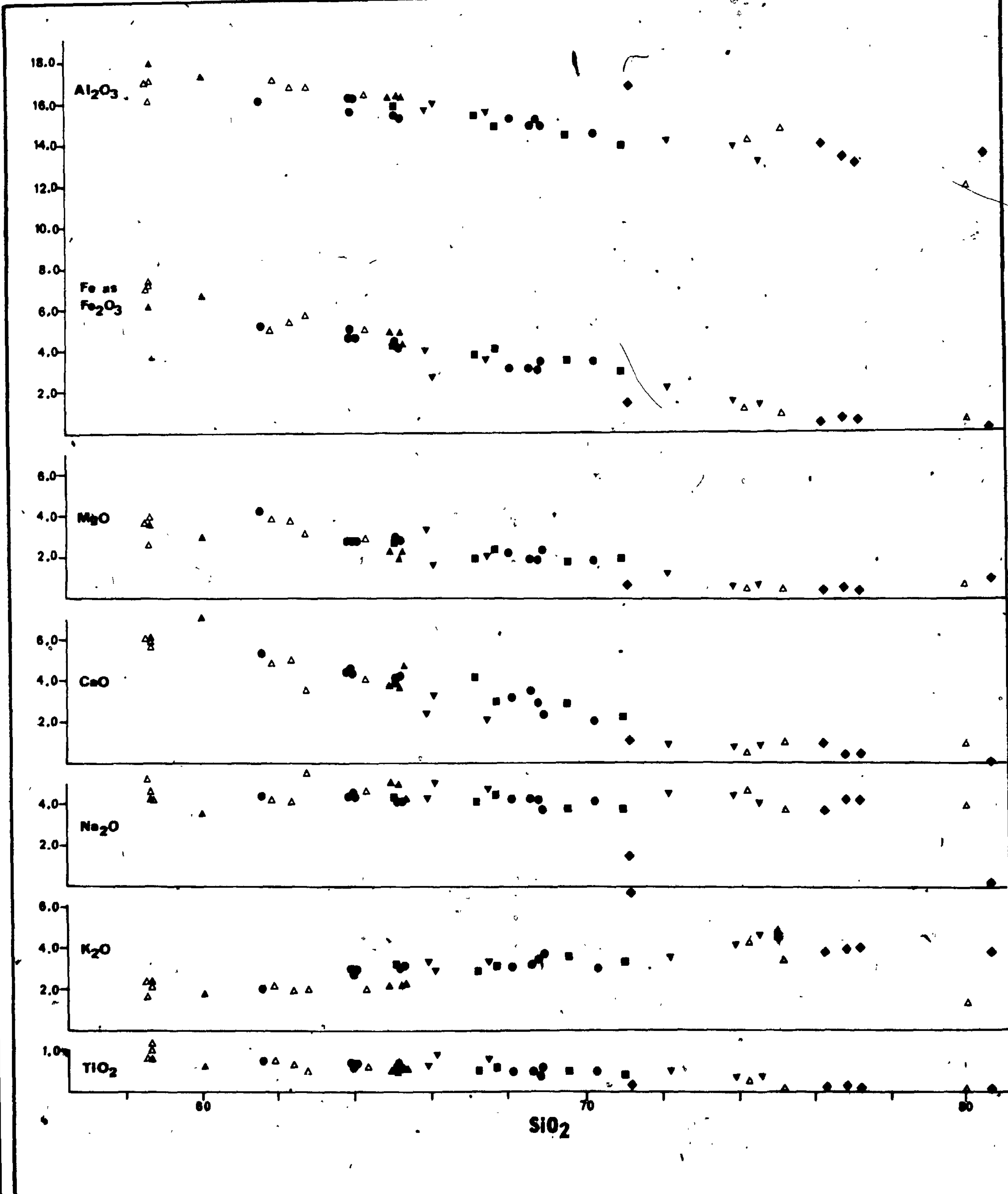
LOCATION of ANALYSED ROCK SAMPLES

Sample location and number

UPPER CRETACEOUS ROCKS

volcanic

plutonic



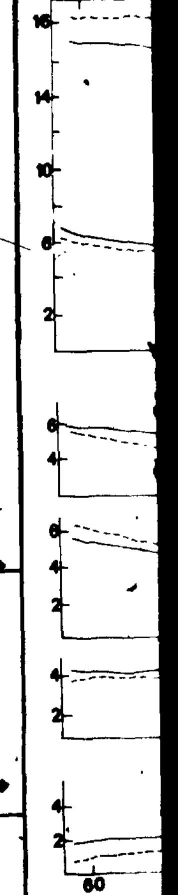
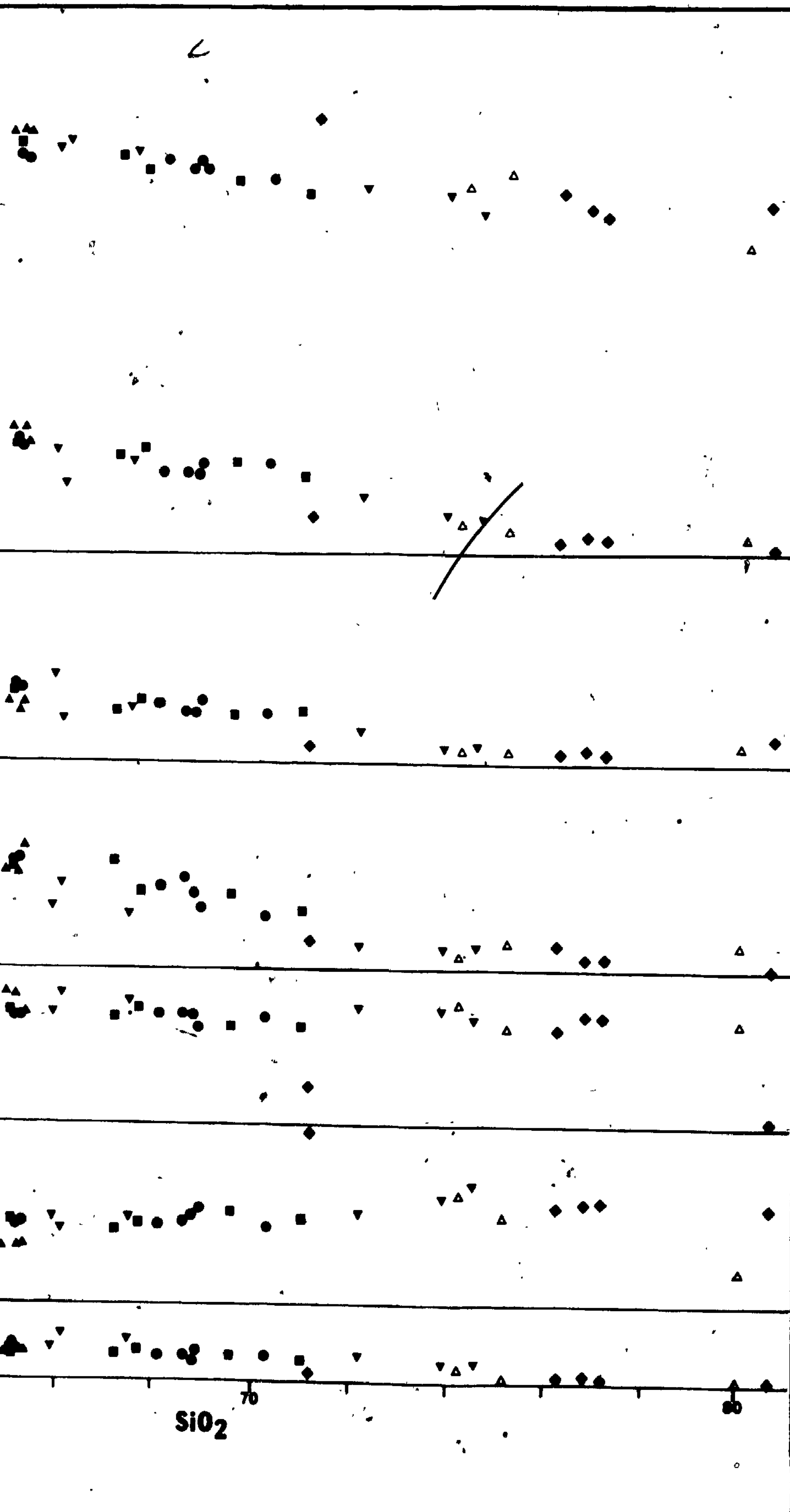


FIGURE 15.
UPPER CRETA
TAHTSA LAKE

ANALYTICAL



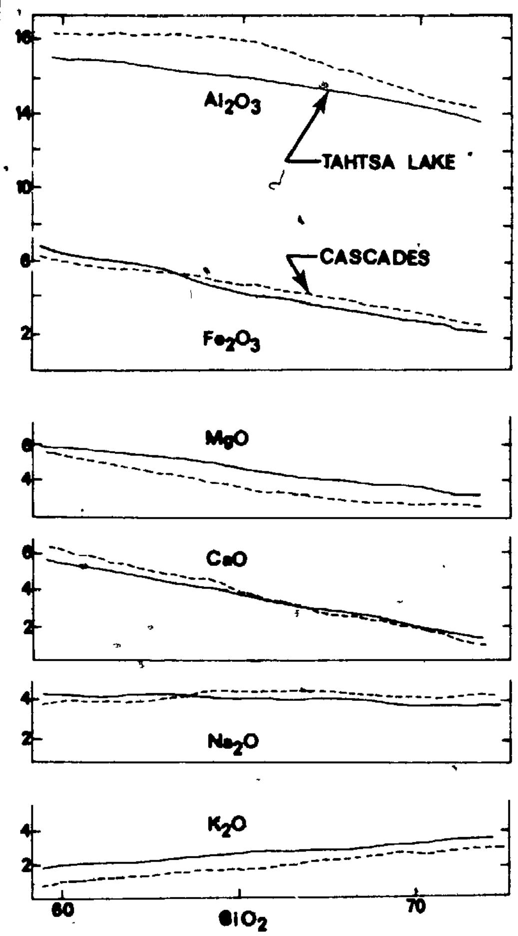


FIGURE 15. HARKER SILICA VARIATION DIAGRAM, UPPER CRETACEOUS VOLCANIC AND PLUTONIC ROCKS, TAHTSA LAKE AREA, BRITISH COLUMBIA.

- ◆ RHYOLITIC INTRUSIONS
- ▼ MT. BOLOM INTRUSIONS
- ■ BULKLEY INTRUSIONS - PORPHYRITIC
- ● BULKLEY INTRUSIONS - GRANITIOID
- ▲ KASALKA INTRUSIONS
- △ KASALKA GROUP

ANALYTICAL DATA GIVEN IN TABLES 9 - 11

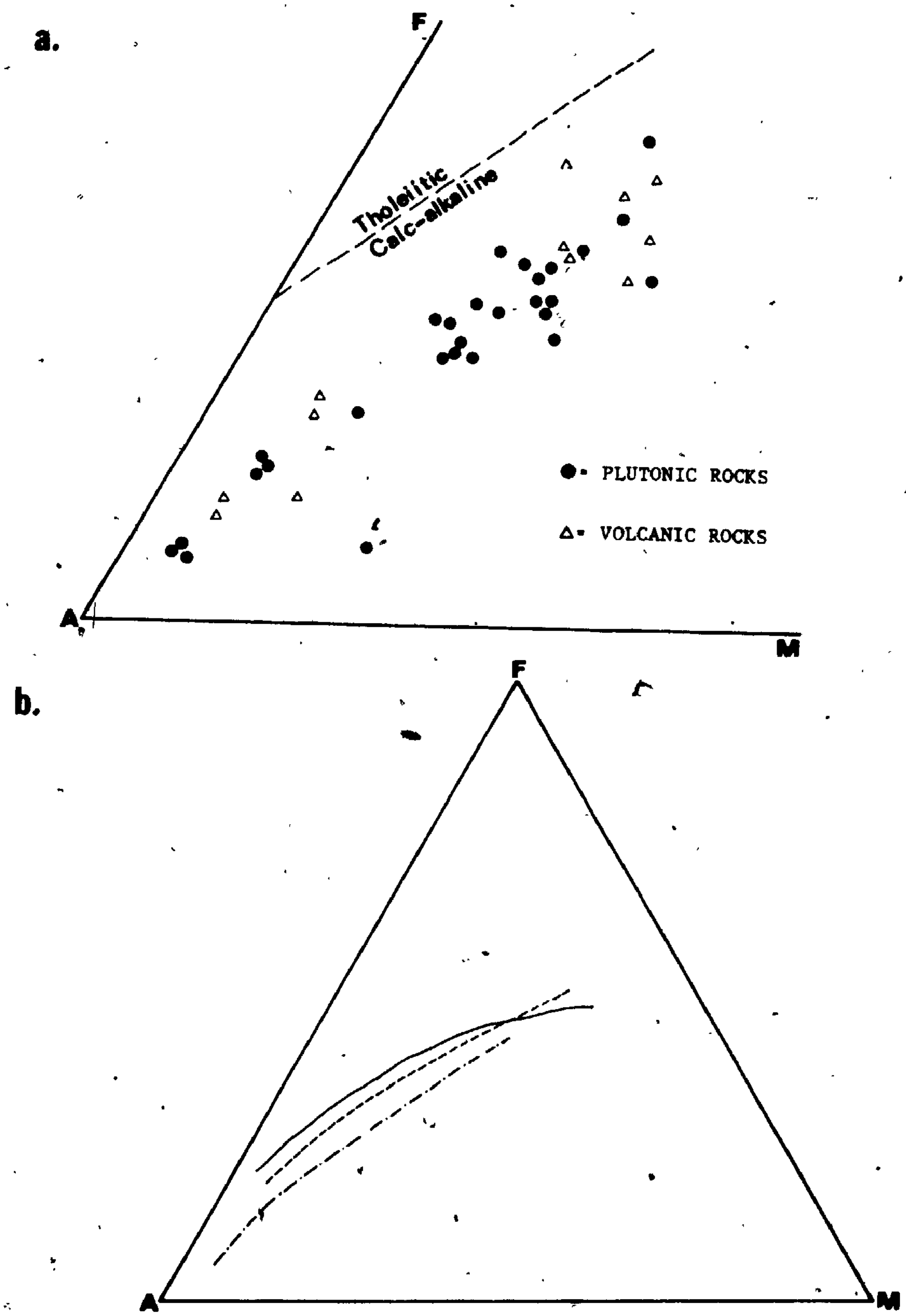


FIGURE 16. AFM ($Na_2O + K_2O$; Total Fe as Fe_2O_3; MgO) plot of analysed samples of Upper Cretaceous volcanic and plutonic rocks, Tahtsa Lake Area. Figure 16b. shows for comparison the AFM trends for Lower California batholith (solid line), Cascades volcanic province (dashed line) and Upper Cretaceous volcanic and plutonic rocks of Tahtsa Lake area.

province (Figure 15).

The relative proportions of alkalies ($Na_2O + K_2O$) total Fe as FeO, and MgO recalculated to 100 percent, are plotted in Figure 16a. All data points plot within the calc-alkali field as defined by Kennedy (1933) and Tilley (1950). The AFM trend line for rocks of the Tahtsa Lake area parallel those for the Lower California Batholith and lavas from the Cascades volcanic province, northwestern United States (Figure 16b). These trends are typical of calc-alkaline rocks and are characterized by a general lack of iron enrichment toward more mafic compositions.

Kasalka Group

Whole rock chemical analyses of Kasalka Group volcanic rocks are presented in Table 8. In general, there is a trend from early salic compositions in the Mt. Baptiste Formation, to intermediate compositions in the Swing Peak Formation, returning to salic compositions in the Bergette Formation. SiO_2 values are between 57 to 64 percent for the intermediate, and between 70 to 80 percent for the salic volcanic rocks, with corresponding ranges of K_2O values between 1.5 to 2.4 and 2.7 to 4.2 percent, respectively. The more salic volcanic rocks are characteristically corundum normative.

The relative proportions of normative orthoclase, plagioclase and quartz, recalculated to 100 percent for analyzed Kasalka Group rocks, are plotted on a ternary diagram (Figure 17a). Samples of intermediate volcanic

TABLE 8. Chemical analyzes (oxides, wt %) and CIPW Molecular norms of typical samples of Kasalka Group volcanic rocks. Analytical procedures given appendix B.

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	57.54	57.60	57.66	60.93	61.40	61.79	63.42	70.89	72.48	73.76	74.79	79.52
TiO_2	0.79	1.38	1.30	0.73	0.63	0.50	0.59	0.39	0.25	0.25	0.07	0.11
Al_2O_3	16.81	15.78	16.78	16.31	16.55	16.67	16.25	16.77	14.46	14.22	14.85	12.10
$*Fe_2O_3$	6.94	7.30	7.09	4.97	5.30	5.59	4.96	2.00	2.11	1.22	0.87	0.80
MnO	0.12	0.09	0.12	0.11	0.10	0.15	0.08	0.07	0.09	0.04	0.05	0.08
MgO	3.57	3.87	2.57	3.77	3.73	3.03	2.85	0.79	0.84	0.53	0.45	0.70
CaO	5.87	5.71	5.63	4.74	4.88	3.40	3.99	1.52	1.23	0.50	1.06	0.94
Na_2O	5.13	4.15	4.54	4.26	4.02	5.39	4.53	4.08	4.90	4.66	3.80	3.95
K_2O	1.56	2.14	2.38	2.14	1.87	1.08	1.96	2.70	2.85	4.15	3.51	1.36
P_2O_5	0.30	0.57	0.61	0.26	0.25	0.24	0.23	0.16	0.09	0.06	0.02	0.04
L.O.I	1.07	1.15	1.50	2.46	1.89	2.18	2.01	2.80	3.24	0.74	1.06	1.34
TOTAL	99.65	99.74	100.18	101.18	100.62	100.92	100.87	102.08	102.54	100.13	100.53	100.94
Q	4.32	8.48	7.41	11.62	13.56	9.34	15.39	30.43	28.48	26.81	33.79	45.39
or	9.30	12.88	14.31	12.75	11.19	11.75	11.70	16.14	17.40	24.66	20.98	8.18
ab	46.49	37.97	41.49	39.58	36.55	48.62	41.11	37.07	42.84	42.08	34.52	36.12
an	18.49	18.46	18.71	20.61	21.87	15.39	18.42	6.59	5.32	2.10	5.19	4.49
di	7.22	5.32	4.57	1.14	0.91	0.00	0.07	0.00	0.00	0.00	0.00	0.00
hy	10.02	10.65	7.39	11.37	12.26	11.55	9.78	2.90	2.37	2.01	1.83	2.49
mt	2.51	3.07	2.98	2.35	2.25	2.10	2.21	0.73	1.32	0.44	0.32	0.29
il	1.11	1.96	1.84	1.03	0.80	0.70	0.83	0.65	0.35	0.35	0.10	0.16
ap	0.63	1.21	1.30	0.55	0.53	0.50	0.49	0.34	0.19	0.13	0.04	0.09
C	0.00	0.00	0.00	0.00	0.00	0.05	0.00	3.25	1.68	1.42	3.23	2.80
An %	28.36	32.71	31.08	34.81	37.43	24.04	30.94	15.08	11.04	4.76	13.07	11.05

* Total Fe as Fe_2O_3; L.O.I. = Loss on ignition

Explanation of column headings

1 Lapilli-tuff, Mt. Baptiste Formation, Mt. Baptiste. Sample D-248A.
2 Porphyritic hornblende latite-andesite, Mt. Baptiste Formation, 4.4 km SE of Laventie Mtn. Sample M-197
3 Porphyritic latite-andesite, member C, Swing Peak Formation, Swing Peak. Sample M-224.
4 Porphyritic hornblende biotite latite-andesite, member A, Swing Peak Formation, south slope Swing Peak ridge. Sample M-214.
5 Porphyritic hornblende latite-andesite, member A, Swing Peak Formation, 5.8 km SW of Swing Peak. Sample M-200.
6 Porphyritic hornblende latite-andesite, member A, Swing Peak Formation, Swing Peak ridge. Sample D-120.
7 Porphyritic latite-andesite, member A, Swing Peak Formation, 5 km NW of Mt. Baptiste. Sample M-225.
8 Rhyolitic lapilli-tuff, Mt. Baptiste Formation, Mt. Baptiste. Sample D-247.
9 Porphyritic dacite, Mt. Baptiste Formation, north slope of Swing Peak. Sample D-168.
10 Banded rhyodacite flow, Mt. Baptiste Formation, 4.5 km SE of Laventie Mtn. Sample M-195.
11 Tuffaceous rhyodacite flow, Bergette Formation, 3.1 km east of Berg Peak. Sample M-178.
12 Rhyolitic tuff, Bergette Formation, 8.1 km east of Berg Peak. Sample M-243.

TABLE 9. Chemical analyzes (oxide, wt %) and CIPW molecular norms of typical samples of the Kasalka Intrusions.

	13	14	15	17	18	A	B	C
SiO_2	57.67	59.10	64.01	64.35	64.47	61.5	73.23	65.5
TiO_2	0.80	0.57	0.54	0.45	0.60	0.7	0.24	0.61
Al_2O_3	17.65	17.06	16.07	16.41	16.17	17.0	14.03	15.65
*Fe_2O_3	6.08	6.58	4.82	4.81	4.13	5.4	2.47	4.70
MnO	0.11	0.15	0.10	0.13	0.07	0.09	0.02	0.09
MgO	3.53	2.91	2.32	1.91	2.31	2.3	0.35	1.86
CaO	6.03	6.97	3.70	3.71	4.65	5.3	1.32	4.10
Na_2O	4.16	3.42	4.94	4.84	4.08	3.9	3.94	3.84
K_2O	2.28	1.72	2.14	2.09	2.22	1.9	4.08	3.01
P_2O_5	0.33	0.31	0.26	0.26	0.26	0.23	0.05	0.23
L.O.I.	1.07	2.08	1.79	2.11	1.01	1.3	-	0.69
TOTAL	99.71	100.87	100.69	101.07	99.97	99.42	-	100.28
Q	6.65	12.59	14.68	15.85	18.47	-	-	-
or	13.63	10.39	12.76	12.48	13.29	-	-	-
ab	37.79	31.39	44.75	43.91	37.13	-	-	-
an	23.02	26.71	15.49	16.90	19.52	-	-	-
di	4.07	5.28	1.06	0.00	1.73	-	-	-
hy	10.58	9.96	7.80	7.55	6.24	-	-	-
mt	2.43	2.21	2.15	2.06	2.23	-	-	-
il	1.13	0.81	0.76	0.63	0.85	-	-	-
ap	0.70	0.66	0.55	0.55	0.55	-	-	-
C	0.00	0.00	0.00	0.06	0.00	-	-	-
An %	31.05	45.97	25.72	27.79	34.45	-	-	-

*Total Fe as Fe_2O_3; L.O.I. = loss on ignition

Explanation of column headings

13 Medium-grained hornblende - biotite - augite diorite, Ox Lake. Sample M-62.

14 Hornblende - augite andesite dyke, north slope, Swing Peak. Sample D-44.

15 Porphyritic hornblende - augite andesite dyke (?), Mt. Baptiste. Sample M-203.

16 Medium - grained hornblende augite diorite, south slope, Rhine Ridge. Sample D-48.

17 Same as M203. Sample D-256.

A Quartz bearing latite-andesite, N. volcano Tumisa, Chile. Seigers et al., 1969.

B Average rhyolite, Cascade Volcanoes. Carmichael et al, 1974.

C Average hornblende - biotite granodiorite. Nockolds, 1954.

TABLE 10. Chemical analyses (oxides, wt %) and CIPW molecular norms of typical samples of Bulkley Intrusions. Analytical procedures given in appendix B.

	18	19	20	21	22	23	24	25	26	27	28	29	30
SiO_2	60.58	62.96	63.06	64.23	64.23	64.30	66.41	66.91	67.30	67.82	68.07	68.77	70.25
TiO_2	0.76	0.69	0.72	0.66	0.64	0.50	0.49	0.58	0.47	0.43	0.41	0.49	0.42
Al_2O_3	15.94	15.51	16.04	15.31	15.76	15.33	15.29	14.67	15.13	14.88	15.06	14.25	13.81
$*Fe_2O_3$	5.16	4.97	4.55	4.38	4.29	4.14	3.75	4.02	3.18	3.17	3.13	3.58	3.17
MnO	0.11	0.09	0.08	0.10	0.05	0.08	0.07	0.04	0.06	0.03	0.03	0.08	0.13
MgO	4.18	2.78	2.77	2.83	2.69	2.91	1.84	2.31	2.15	1.93	1.85	1.77	1.84
CaO	5.18	4.52	4.25	4.09	3.92	4.17	4.16	2.85	3.14	3.36	2.83	2.77	2.28
Na_2O	4.37	4.21	4.21	4.07	4.04	4.03	4.05	4.37	4.28	4.14	4.14	3.73	3.75
K_2O	2.09	2.82	2.90	2.95	3.03	3.07	2.81	2.99	3.11	3.14	3.40	3.51	3.32
P_2O_5	0.30	0.32	0.29	0.30	0.26	0.28	0.21	0.27	0.24	0.20	0.19	0.20	0.21
L.O.I.	1.03	0.63	1.02	1.16	2.34	0.83	1.71	0.65	0.60	0.94	0.84	0.51	1.86
TOTAL	99.70	99.50	99.89	100.98	101.25	99.73	100.79	99.66	99.60	100.04	99.95	99.66	101.04
Q	9.87	13.60	13.56	15.65	15.67	15.35	19.56	19.08	19.28	20.52	20.50	23.33	26.12
or	12.45	16.88	17.32	17.64	18.12	18.34	16.83	17.87	18.55	18.76	20.30	21.09	19.94
ab	39.56	38.29	38.22	36.93	36.71	36.59	36.87	39.70	38.79	37.59	37.57	34.06	34.23
an	17.86	15.29	16.49	14.98	16.11	13.84	15.46	11.72	13.01	12.89	12.61	11.98	10.12
di	4.88	4.26	2.35	2.88	1.49	3.40	3.27	0.66	0.92	2.13	0.28	0.55	0.00
hy	11.82	8.23	8.78	8.70	8.89	8.56	5.51	8.13	7.14	5.93	6.64	6.58	6.95
mt	1.87	1.80	1.65	1.59	1.56	1.50	1.37	1.46	1.15	1.15	1.13	1.31	1.16
il	1.07	0.97	1.01	0.93	0.90	0.83	0.69	0.82	0.66	0.61	0.58	0.69	0.59
ap	0.63	0.68	0.61	0.63	0.55	0.53	0.45	0.57	0.51	0.42	0.40	0.43	0.45
An %	31.10	28.54	30.14	28.82	30.51	28.85	29.54	22.80	25.12	25.54	25.12	26.01	22.81

* Total Fe as [illegible] L.O.I. = Loss on ignition

Explanation of column headings

18 Medium-grained porphyritic biotite quartz diorite, Coles Creek prospect. Sample BZ-14.
19 Medium-grained hornblende - biotite granodiorite, east contact Sibola Stock, 1.9 km NW of Sibola Pk Sample M-95
20 Medium-grained biotite quartz diorite, Mt Baptiste. Sample D-255
21 Medium-grained hornblende-biotite granodiortie, Sibola Stock, 3.5 km N of Mt. Sweeney. Sample M-120.
22 Medium-grained porphyritic hornblende-biotite granodiorite, Coles Creek. Sample CC-3-571
23 Medium-grained hornblende-biotite granodiorite, Sibola Stock, Mt Sweeney Sample M-238
24 Medium-grained porphyritic hornblende-biotite granodiorite, Ox Lake Sample OL-18-984
25 Coarse-grained porphyritic hornblende - biotite quartz monzonite, Bergette prospect. Sample M-116.
26 Medium grained hornblende-biotite granodiorite, Sibola Stock, 3.2 km NW of Mt. Sweeney. Sample M-137
27 Medium-grained hornblende-biotite granodiorite, Sibola Stock, Whiting Creek. Sample WC-7-47
28 Medium-grained hornblende-biotite granodiorite, Sibola Stock, Whiting Creek Sample M-77.
29 Medium-grained porphyritic hornblende-biotite quartz monzonite, Bergette Prospect Sample M-128.
30 Medium-grained porphyritic quartz monzonite dyke, 3.2 km NW of Mt. Sweeney Sample M-142

TABLE 11. Chemical analyses (oxide, wt %) and CIPW molecular norms of typical samples of rhyolitic intrusions (31 - 35) and Mt. Bolom Intrusions (36 - 41). Analytical procedures given in appendix B.

	31	32	33	34	35	36	37	38	39	40	41
SiO_2	70.62	75.83	76.41	76.76	80.28	64.99	65.27	66.68	71.55	73.37	74.06
TiO_2	0.22	0.10	0.08	0.07	0.08	0.64	0.86	0.79	0.56	0.40	0.35
Al_2O_3	16.76	13.99	13.40	13.18	13.68	15.54	15.79	15.44	14.05	13.83	13.16
$*Fe_2O_3$	1.50	0.56	0.66	0.61	0.41	4.03	3.83	3.57	2.34	1.69	1.48
MnO	0.23	0.05	0.04	0.05	0.00	0.10	0.10	0.09	0.15	0.08	0.04
MgO	0.71	0.39	0.39	0.33	0.98	3.28	1.71	2.07	1.28	0.62	0.69
CaO	1.08	1.08	0.45	0.40	0.13	2.44	3.32	2.12	1.04	0.80	0.87
Na_2O	1.48	3.69	4.21	4.15	0.19	4.26	4.94	4.68	4.55	4.38	3.99
K_2O	6.70	3.78	3.83	3.95	3.89	3.27	2.86	3.23	3.57	4.14	4.71
P_2O_5	0.06	0.02	0.04	0.03	0.02	0.31	0.31	0.34	0.16	0.06	0.06
L.O.I.	2.54	2.13	1.04	0.68	1.62	2.04	1.52	1.18	0.91	0.61	0.92
TOTAL	101.90	101.62	100.55	100.21	101.28	100.90	100.51	100.19	100.16	99.98	100.33
Q	30.87	34.61	33.30	33.71	60.27	16.22	15.29	18.33	25.41	27.30	27.90
or	40.49	22.62	22.84	23.57	23.92	19.48	17.03	19.24	21.29	24.70	28.15
ab	13.59	33.56	38.16	37.64	1.78	38.56	44.72	42.37	41.24	39.71	36.24
an	5.08	5.30	1.99	1.81	0.54	10.18	12.57	8.39	4.16	3.62	3.97
di	0.00	0.00	0.00	0.00	0.00	0.00	1.61	0.00	0.00	0.00	0.00
hy	3.10	1.41	1.49	1.32	2.99	11.13	5.53	7.23	4.61	2.45	2.52
mt	0.56	0.20	0.24	0.22	0.15	1.45	1.38	1.29	0.84	0.61	0.54
il	0.31	0.14	0.11	0.10	0.12	0.90	1.21	1.11	0.79	0.56	0.49
ap	0.13	0.04	0.08	0.06	0.04	0.65	0.56	0.72	0.34	0.13	0.13
C	5.86	2.11	1.77	1.57	10.19	1.42	0.00	1.32	1.31	0.92	0.07
An %	27.22	13.63	4.96	4.58	23.21	20.89	21.94	16.51	9.17	8.35	9.88

* Total Fe as Fe_2O_3; L.O.I. = loss on ignition.

31 Porphyritic rhyodacite dyke, Whiting Creek Prospect. Sample M-79.
32 Aphanitic rhyodacite , Whiting Creek Prospect. Sample M-106.
33 Fine grained porphyritic rhyodacite dyke, north shore Troitsa Lake. Sample D-193.
34 Porphyritic rhyodacite dyke, north shore, Troitsa Lake. Sample D-207.
35 Porphyritic rhyodacite dyke, Whiting Creek Prospect. Sample WC-11-107
36 Medium grained porphyritic hornblende biotite granophyre, Mt. Bolom Stock, N. tip of Blanket Lakes. Sample D-201.
37 Medium grained porphyritic hornblende-biotite granophyre, Mt. Bolom Stock, 7.8 km NNE of Mt. Bolom. Sample M-199.
38 Medium grained porphyritic hornblende-biotite granophyre, Mt. Bolom Stock 5 km N of Mt. Bolom. Sample M-192.
39 Medium grained porphyritic hornblende-biotite granophyre, Mt. Bolom Stock 5 km N of Mt. Bolom. Sample M-194.
40 Fine grained porphyritic biotite granophyre dyke, 1.5 km S of Swing Peak. Sample M-222.
41 Fine grained porphyritic hornblende-biotite granophyre, Mt. Bolom Stock 2.5 km E of Mt Bolom. Sample D-202.

rocks from the Mt. Baptiste and Swing Peak Formations, fall mainly within the latite-andesite field, as defined by Streckeisen (1967), while salic volcanic rocks from the Mt. Baptiste and Swing Peak Formations are within the dacite and rhyodacite fields. The lack of samples in the lower part of the dacite field corresponds to an absence of samples with SiO_2 values between 64 to 70 percent. This suggests that the volcanic rocks of the Kasalka Group can be divided into two distinct assemblages or populations based on composition, i.e., a bimodal volcanic assemblage. More detailed sampling is required to determine if this is a real feature of these rocks. Andesite rocks of the Kasalka Group have chemical compositions similar to those of the Andesite Formation of Chile (compare analyses 5 and 6 to A in Table 9). The rhyolitic rocks are similar to the average rhyolite of Cascade Volcanoes (B in Table 9).

Kasalka Intrusions

Chemical analyses of 5 typical samples of the Kasalka Intrusions are presented in Table 9. These rocks have chemical compositions very similar to intermediate flows of the Kasalka Group, especially in terms of K_2O content (Figure 18). As would be expected, the Kasalka Intrusions also fall within the latite-andesite field of Figure 17a.

Bulkley Intrusions

Chemical analyses of typical samples of the Bulkley Intrusions in the Tahtsa Lake area are given in Table 10. These samples contain between 60 to 71 percent SiO_2 and

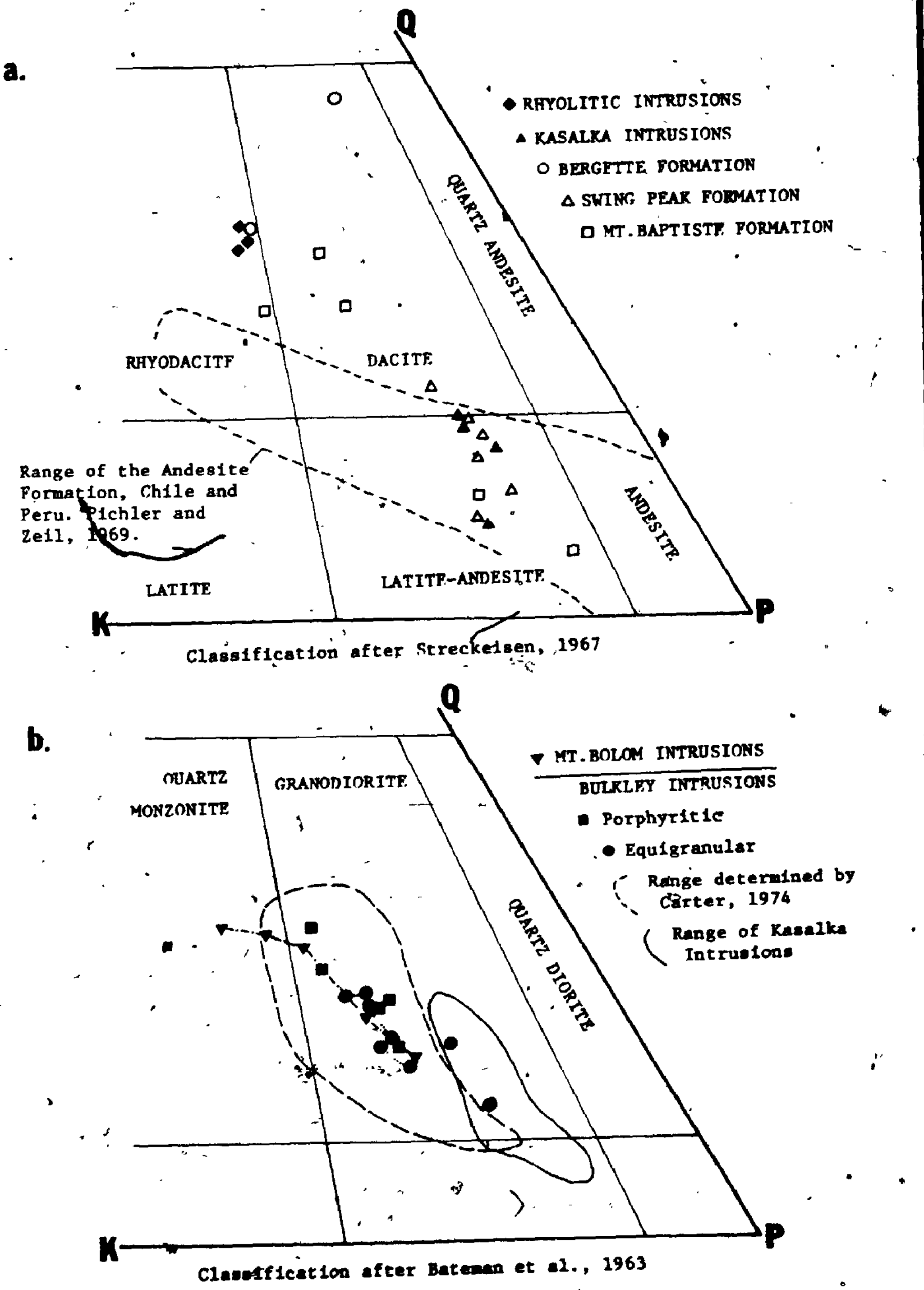


FIGURE 17. Plots of normative quartz (Q), plagioclase (P), and orthoclase (K) recalculated to 100 percent for Upper Cretaceous volcanic and plutonic rocks, Tahtsa Lake area.

2.0 to 3.6 percent K_2O (Figure 18). The Bulkley Intrusions differ from the Kasalka Group volcanic rocks and Kasalka Intrusions by having more K_2O at any given SiO_2 content. The only exception is the quartz diorite at Coles Creek (Analysis 18) which has a composition similar to latite-andesite of the Swing Peak Formation (Analysis 4, Table 8).

The relative proportions of normative quartz, plagioclase and orthoclase recalculated to 100 percent for analyzed samples of the Bulkley Intrusions, are plotted in Figure 17b. With the exception of the two samples of quartz diorite, all data points fall within the field for the Bulkley Intrusions as defined by Carter (1974). On a normative basis, these rocks are classified as granodiorites. The data points for the porphyritic intrusions cluster about the trend line defined by analyses of the Sibola Stock. This suggests that there is no significant difference in the relative proportions of major oxides for the porphyritic and equigranular phases of the Bulkley Intrusions. All of these rocks have compositions similar to average granodiorite as determined by Nockolds (c in Table 9).

Rhyolitic Intrusions

Three samples of the Whiting Creek porphyritic rhyodacite, and two samples of the porphyritic rhyodacite dyke on the north shore of Troitsa Lake were analyzed (Table 11). The Whiting Creek samples (Analyses 31, 32, 35, Table 11), have SiO_2 values between 70 to 81 percent with

□ Nanika Intrusions - Berg porphyritic quartz monzonite
○ Coast Intrusions - Berg quartz diorite
▼ Mt. Bolom Intrusions - porphyritic granophyre
◆ Porphyritic rhyodacite dyke, Troitsa Lake
● Bulkley Intrusions - granodiorite, quartz diorite
⊕ Bulkley Intrusions - rhyodacite
■ Bulkley Intrusions - porphyritic granodiorite
■ Bulkley Intrusions - porphyritic granodiorite (Carter, 1974)
▲ Kasalka Intrusions - latite-andesite, diorite
△ Kasalka Group - andesitic and rhyodacitic volcanic rocks

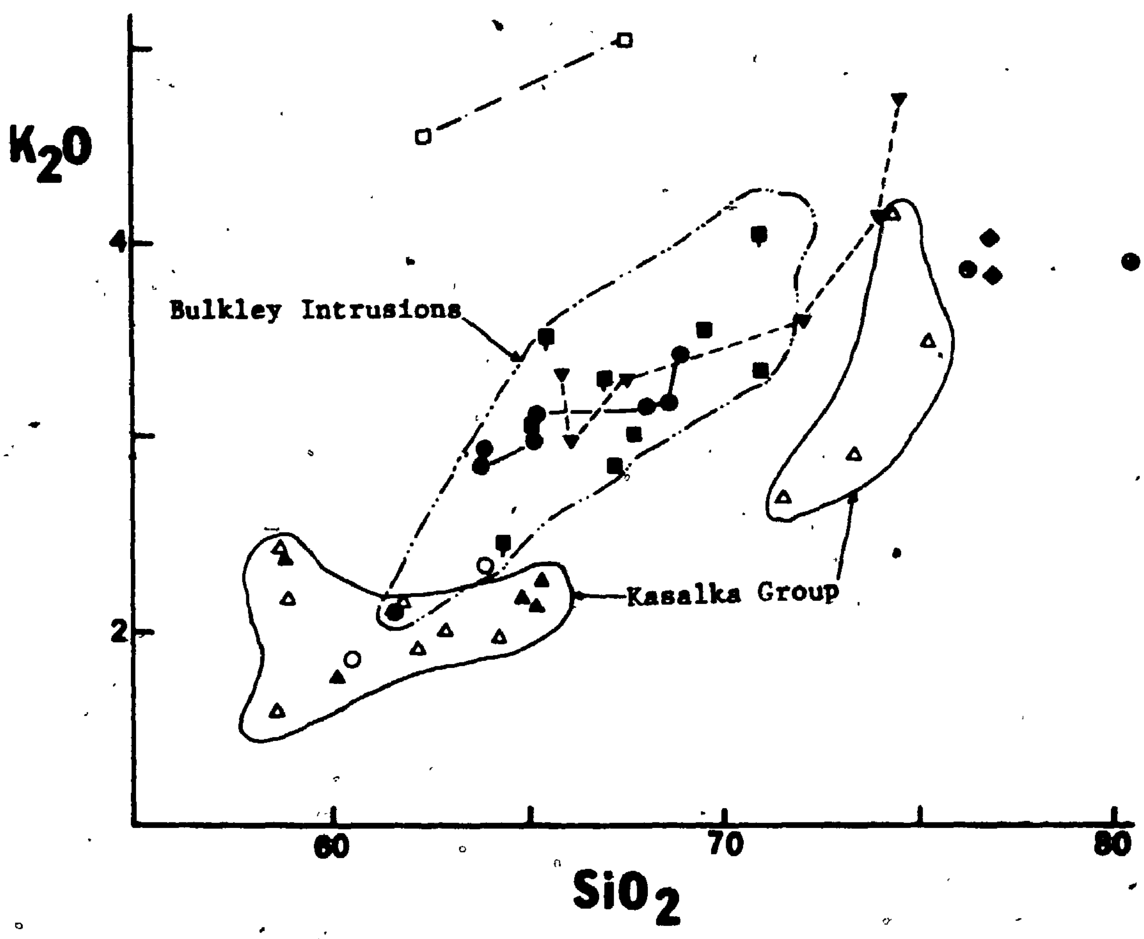


FIGURE 18. Plot of K_2O versus SiO_2 (wt.percents) for analysed samples of Upper Cretaceous volcanic and plutonic rocks, Tahtsa Lake area. Analytical data is given in tables 8-12.

variable K_2O and Na_2O contents. This variability reflects different intensities of hydrothermal alteration. The samples from Troitsa Lake (Analyses 33, 34, Table 11), are very similar in composition to the rhyodacite flows of the Bergette Formation (e.g. Analysis 11), particularly in terms of K_2O content (Figure 18). Both the Whiting Creek and Troitsa Lake rhyodacites are corundum normative.

Mt. Bolom Intrusions

The chemical composition of 5 samples of porphyritic granophyre from the Mt. Bolom stock and a related dyke on Swing Peak, are given in Table 11. These samples have between 65 to 75 percent SiO_2, with a corresponding range of K_2O from 2.9 to 4.7 percent. The more differentiated phases of the Mt. Bolom Intrusions tend to be more silicic than those of the Bulkley Intrusions, falling within the quartz monzonite field (Figure 7b). This is also shown on the K_2O-SiO_2 variation diagram (Figure 18) where the trend line for the Mt. Bolom Intrusions overlaps and appears to be a continuation of that determined for the Bulkley Intrusions. Another difference between the Bulkley and Mt. Bolom Intrusions is that the latter tends to be corundum normative.

Comparison of Upper Cretaceous and Tertiary Rocks

Carter (1974) has shown that the Upper Cretaceous Bulkley Intrusions are less potassic than the Eocene Nanika Intrusions for any given SiO_2 content. This is best shown on the K_2O-SiO_2 variation diagram (Figure 18) where

TABLE 12. Chemical analyzes (oxide, wt %) of Berg Quartz diorite. Analytical procedures given in Appendix B.

	42	43
SiO_2	59.46	62.86
TiO_2	0.85	0.75
Al_2O_3	16.83	16.21
*Fe_2O_3	5.91	4.96
MnO	0.13	0.10
MgO	3.56	2.79
CaO	5.98	4.57
Na_2O	3.85	4.07
K_2O	1.82	2.29
P_2O_5	0.33	0.28
L.O.I.	0.79	1.21
TOTAL	99.51	100.09
Q	11.48	15.29
or	10.92	13.72
ab	35.12	37.07
an	23.64	19.48
di	3.47	1.35
hy	11.31	9.64
mt	2.16	1.80
il	1.20	10.6
ap	0.70	0.59
C	0.00	0.00
An %	40.23	34.45

* Total Fe as Fe_2O_3; L.O.I. = Loss on ignition.

Explanation of column headings.

42 Medium-grained hornblende-biotite quartz diorite, 0.5 km east of Berg prospect. Sample M 153.

43 Medium-grained hornblende-biotite quartz diorite, 2 km south of Berg prospect. Sample M 155.

data points for two analyses of the Berg quartz monzonite (data from Carter, 1974) fall well above the trend line for the Bulkley Intrusions. By contrast, two analyses of the Berg quartz diorite (Table 12), which is believed to be part of the Coast Intrusions, plot within the fields defined for the Bulkley and Kasalka Intrusions (Figure 18). On a chemical basis, these rocks cannot be distinguished from their older counterparts.

CHAPTER 5

EVOLUTION OF UPPER CRETACEOUS VOLCANIC AND PLUTONIC CENTERS

5.1 General Statement

Rocks of the Kasalka Group represent the few surviving remains of a continental volcanic terrain of unknown thickness and extent that covered the Tahtsa Lake area in the earliest Upper Cretaceous. Preservation of these rocks was enhanced by subsidence of fault blocks, particularly in the Kasalka Range. Plutonic rocks of comparable age and composition have been unroofed in areas peripheral to the Kasalka Range and these may be genetically related to the volcanic rocks. This possibility will be discussed in this chapter, using the geologic, geochronologic and compositional data presented earlier. Particular emphasis is given to the timing of porphyry copper occurrences in the volcanic-plutonic cycle.

5.2 Deposition of the Kasalka Group

The Kasalka Group is a complex mixture of calc-alkaline volcanic and volcanic sedimentary rocks which overlie older rocks with angular discordance. In the Kasalka Range, the stratigraphic succession can be divided into a lower unit of predominantly felsic pyroclastic rocks (Mt. Baptiste Formation) and an upper unit of andesitic lahar and flows (Swing Peak Formation). This is interpreted to mean a change from explosive rhyolitic volcanism to construction of andesitic cones with time. In the Tahtsa Range, the rhyolitic flows of the Bergette Formation overlie the Swing Peak Formation, and represent a later episode of extrusive activity. The relatively thin sequence of oxidized pebble conglomerate and sandstone at the base of the Kasalka Group, suggests that uplift and peneplanation preceded deposition of Upper Cretaceous volcanic rocks.

Mt. Baptiste Formation

The Mt. Baptiste Formation is a complex mixture of coarse and fine-grained rhyodacitic lapilli-tuffs and breccias, interbedded with rhyodacite and latite-andesite flows. The nature of the volcanic assemblage suggests alternating episodes of explosive eruption and quiet effusion from numerous vents. Most of the fine-grained pyroclastic rocks have well-developed horizontal bedding and are unwelded and well-sorted. These features are characteristic of rocks of air fall origin (Fisher 1966). However, some of the lapilli-tuff beds have eutaxitic textures, and an ash flow or base surge origin is favored for these rocks (Ross, 1961).

Volcanic terrains, similar to that represented by the Mt. Baptiste Formation, are common in the North American cordillera, particularly in areas where calderas are located (e.g., Lambert, 1974; Marjaniemi, 1969). Evolution of such terrains is believed to be the result of explosive and periodic emptying of vertically-zoned magma chambers. The volcanic cycle begins with upwelling of magma of intermediate composition, which upon cooling, begins to concentrate volatile-rich rhyolitic liquid in the top of the magma chamber in the manner described by Kennedy (1955). When volatile pressure exceeds confining pressure, rupturing of the magma chamber may occur, with volatiles escaping violently along ring and radial fracture zones. Airborne volcanic debris is subsequently deposited over an extensive area. Caldera collapse may accompany rapid evacuation of the magma chamber, followed by quiet effusion of rhyodacitic and finally andesitic lava (Marjaniemi, 1969); Lambert, 1974). Partitioning of alkalies, specifically potassium, into high pressure aqueous vapor phase prior to eruption, may explain the apparent peraluminous (corundum normative) composition of the rhyolitic volcanic rocks (Burnham, 1967). Under such conditions, muscovite could become the stable K-bearing phase, thus explaining the predominance of muscovite over K-feldspar in these rocks.

Swing Peak Formation

The Swing Peak Formation includes massive flows of latite-andesite separated by a thick sequence of stratified lahar. The composition of the volcanic rocks and the nature of the stratigraphic succession are characteristic of stratovolcanoes, both in the Andes of South America (McBirney, 1969 ; Siegers, et.al., 1969) and in the Cascade volcanic province of North America (Chayes, 1969; Lydon, 1968). Rocks of the Swing Peak Formation are believed to be the remains of similar volcanic structures, which were present in the Tahtsa Lake area during Upper Cretaceous time.

The relatively narrow range of compositions of flows of the Swing Peak Formation suggests no significant degree of differentiation took place between successive eruptions. Oscillatory-zoning of plagioclase phenocrysts may reflect fluctuations of pressure resulting from periodic surges of magma into the magma reservoir. The absence of vesicles and presence of euhedral phenocrysts in the flows is taken as evidence that the magma was relatively deficient in volatiles, and was extruded in a partly crystallized state. Columnar jointing in some of the flows suggests cooling was relatively slow after initial effusion. The pervasive and ubiquitous propylitic alteration of these volcanic rocks is probably caused by convective circulation of heated meteroric waters through the more permeable parts of the volcanic succession. Major faults were important channel-ways for these fluids.

Lahar of the Swing Peak Formation is similar to that of the Tuscan Formation of the Mt. Lassen area in California (Lydon, 1968) and Ellensburg Formation of south central Washington (Schminke, 1967). Such deposits are probably formed by addition of magmatic or meteoric water to brecciated material lying on the unstable slopes of growing volcanoes resulting in downslope movement

(Anderson, 1933; Lydon, 1968). Areas between the volcanic cones are gradually filled with thick deposits of stratified laharic debris which is locally reworked by stream action. Flows of latite-andesite interbedded with these rocks indicate that volcanic activity was contemporaneous with sedimentation.

Bergette Formation

In the Tahtsa Range, rhyolitic flows of the Bergette Formation overlie rocks correlated with the Swing Peak Formation. The flows have almost the same composition as those of the Mt. Baptiste Formation and a similar origin is implied. Similar rocks in the Bennett Lake area of the Yukon Territory (Lambert, 1974) are believed to be related to late resurgent doming and rhyolitic ring dyke formation.

5.3 Emplacement of Plutonic Rocks

A wide variety of Upper Cretaceous plutonic rocks have been unroofed in the Tahtsa Lake area. These can be divided on the basis of age, composition and mode of occurrence into the Kasalka, Bulkley and Mt. Bolom Intrusions.

Kasalka Intrusions

The oldest plutonic rocks in the Tahtsa Lake area are the Kasalka Intrusions. These include both fine-grained prophyritic and medium-grained equigranular rocks of dioritic composition and the porphyritic dacite at Coles Creek. The fine-grained rocks occur as dykes and sills within and immediately below the Swing Peak Formation. These intrusions have the same composition and texture as the latite-andesite flows of the Swing Peak Formation and there can be little doubt that the dykes are feeders for the volcanic rocks. The lack of wallrock deformation, absence of contact metamorphism and the fine-grained porphyritic texture of the dykes, suggests they were passively intruded and that they crystallized rapidly. Locally, the dykes are observed to grade into tuff-breccia which terminates below horizons of lahar. This suggests that as magma approached the surface, rapid crystallization and brecciation took place, with the brecciated material being pushed upward to the surface. Lydon (1968) has proposed a similar origin for the tuff-breccia dykes within the Tuscan Formation, and suggests such dykes may contribute directly to some of the laharic deposits within the formation.

Several small stocks of medium-grained diorite crop out in the area peripheral to the Kasalka Range. The diorites have approximately the same composition as the latite-andesite dykes and flows within the Kasalka Range, suggesting they are comagmatic with these rocks. The coarser-grained texture of the diorite may reflect a deeper level of erosion in the area outside of the Kasalka Range.

The porphyritic dacite at Coles Creek appears to be a laccolith-like intrusion emplaced along the Kasalka-Hazelton Group interface (MacIntyre, 1974). Felsic pyroclastic rocks of the Mt. Baptiste Formation form the roof of the laccolith. The dacite is petrographically similar to dacite and latite laccoliths in the Upper Cretaceous volcanic successions of south central Arizona. Watson (1968) suggests intrusions of this type form by injection of gas-charged melts into areas of low confining pressure, particularly at the base of comagmatic volcanic piles. The rapid decrease in confining pressure may result in a sudden expansion and escape of gases, followed by quenching, and in places, autobrecciation of the remaining melt. Breccia and pebble dykes associated with the laccoliths may represent escape channels for the liberated volatiles.

Bulkley Intrusions

The Bulkley Intrusions are the most volumetrically significant of the plutonic rocks in the Tahtsa Lake area. These rocks have a relatively narrow range of compositions, being predominantly granodiorite with subordinate quartz monzonite and quartz diorite. As a whole, the Bulkley Intrusions are more potassic than the Kasalka Intrusions, with the two groups having divergent compositional trends. However, the apparent intersection of these trends in the vicinity of quartz diorite on the K_2O-SiO_2 variation diagram (Figure 18) could indicate that they were derived from a common parent magma of this composition. The greater K_2O content of the Bulkley Intrusions with increasing SiO_2 probably reflects the more differentiated nature of these rocks. Conversely, the relatively small K_2O content of the more silicic members of the Kasalka Intrusions may reflect removal of alkalies by the processes described earlier. Therefore, there appears to be no reason to invoke the presence of two chemically distinct magmas, in spite of the apparent differences in composition between the two groups of intrusions. Rather, it is suggested that there is a continuum of compositions between diorite of the Kasalka Intrusions and quartz diorite of the Bulkley Intrusions, the former being the subvolcanic equivalent of the latter. Tilling (1974) arrived at a similar conclusion for dioritic and granodioritic phases of the Boulder Batholith.

The Bulkley Intrusions are restricted to the area peripheral to the Kasalka Range, where both coarse-grained equigranular and porphyritic rocks have been unroofed. These intrusions, although texturally distinct, are not mutually exclusive to one another, and, in fact, usually occur together either as a group of plutons or as a large multi-phase stock. For example, at Coles Creek, a medium-grained dyke-like mass of equigranular quartz diorite crops out less than 1500 meters from a younger porphyritic granodiorite stock. Similarly, the Sibola Stock, which is composed of coarse-grained equigranular granodiorite, is intruded by later porphyritic rhyodacite and quartz monzonite phases. The sequence of intrusion, from equigranular quartz diorite to late porphyritic quartz monzonite, is not restricted to the Tahtsa Lake area. In fact, it is a common association in many other areas, particularly where the porphyritic intrusions are associated with porphyry copper deposits (e.g., Lowell and Guilbert, 1970; Stringham, 1966; Northcote, 1969). This suggests a common genetic origin for plutonic complexes of this type.

The progressive increase in the SiO_2 and K_2O content of successively younger intrusions within a plutonic complex is probably due to magmatic differentiation. In the case of the Bulkley Intrusions, the initial pulse of magma was probably quartz diorite, or diorite in composition as indicated by narrow chilled zones of this composition enclosing the larger stocks. The relatively fresh, coarse-grained, equigranular texture of the main mass of the stocks suggests that crystallization took place slowly over a long period of time, and under relatively stable conditions of temperature and pressure. The paucity of extensive hydrothermal alteration and the presence of wide contact metamorphic aureoles about the intrusions, suggests cooling was primarily by outward conduction of heat from a water deficient melt. Crystallization probably began at the contact of the stocks and proceeded inward towards the core with residual melts becoming progressively enriched in K and Si by processes of fractional crystallization (e.g., Bateman, et.al., 1963).

The porphyritic granodiorite stocks at Ox Lake, Coles Creek and Huckleberry Mountain may have been emplaced when residual melts of granodiorite composition broke through the quartz dioritic shell of a large magma reservoir at depth, and rose as diapirs of phenocryst-rich magma into overlying rocks (Figure 19a). The subsequent

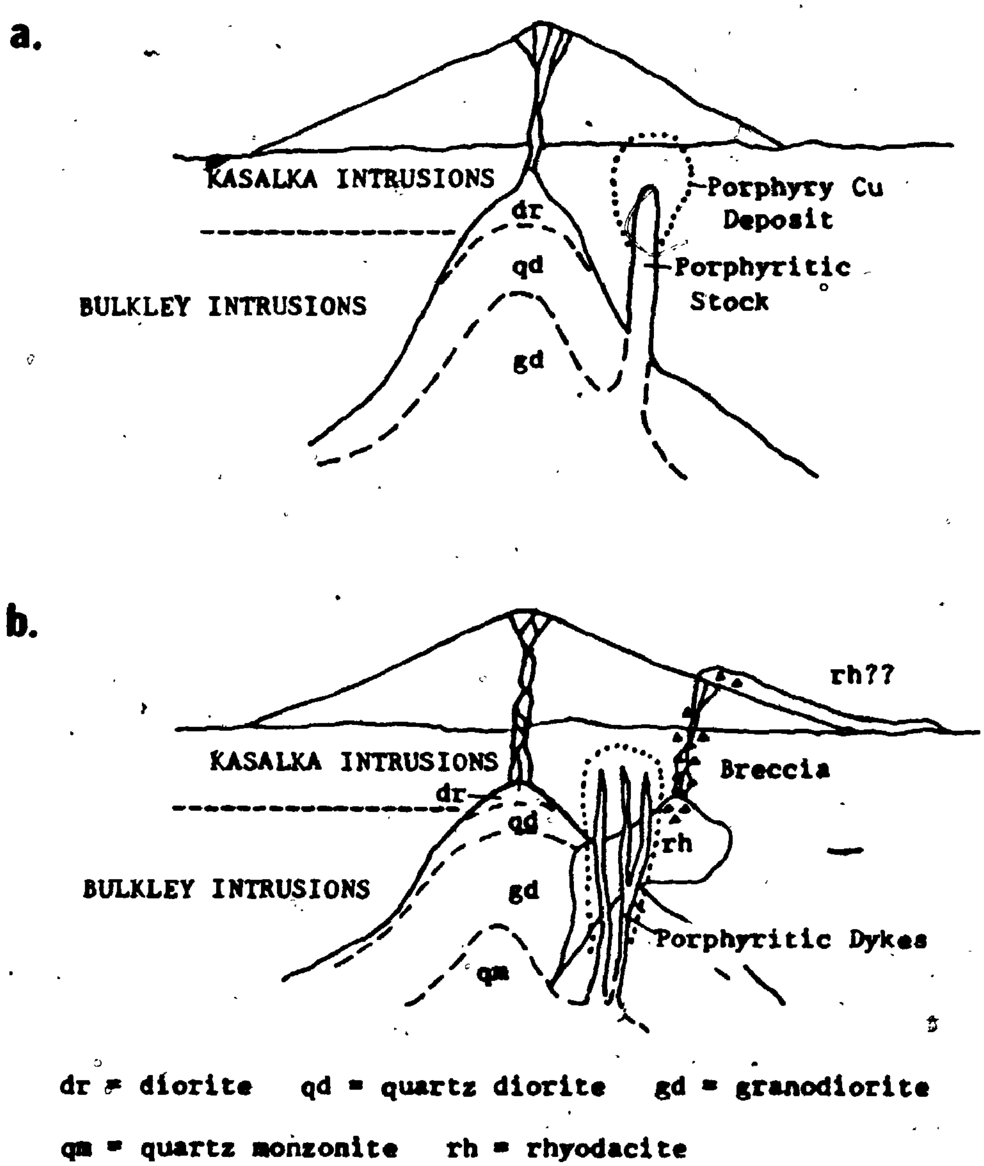


FIGURE 19. MODELS FOR EVOLUTION OF PLUTONIC CENTERS IN THE TAHTSA LAKE AREA. SEE TEXT FOR EXPLANATION.

reduction in temperature and pressure as the magma approached the surface, resulted in rapid crystallization of the remaining melt, thus producing the porphyritic textures observed. This hypothesis is in part supported by examination of drill holes into the core zones of the porphyritic intrusions, which indicate a progressive change to coarser-grained, more equigranular textures with depth. Sillitoe (1973) has documented similar relationships for porphyritic stocks in the Central Andes of South America, although elsewhere, porphyritic stocks have been shown to have no obvious relationships to larger plutonic bodies at depth.

The porphyritic quartz monzonite dykes within the Sibola and Troitsa stocks probably formed in a manner similar to that of the porphyritic granodiorite stocks at Ox Lake, etc., with the exception that here injection of rhyodacite preceded emplacement of the late porphyritic dykes. Furthermore, the more potassic composition of the quartz monzonite dykes, as compared with the porphyritic granodiorite at Ox Lake, etc., suggests that crystallization and differentiation of the Sibola and Troitsa stocks was almost complete at the time of dyke formation.

The rhyodacite intrusions within the Sibola and Troitsa stocks are rather enigmatic rocks, being considerably more siliceous, but less potassic than either earlier or later phases. The peraluminous compositions (corundum normative) of the rhyodacites, are consistent with the observed mineralogy of these rocks which contain mainly quartz, muscovite and albite. Such rocks could form in a manner similar to that proposed for peraluminous volcanic rocks of the Mt. Baptiste and Bergette Formation. That is, during the final stages of crystallization of the Troitsa and Sibola Stocks, the core was probably occupied by a crystal mush of quartz monzonite composition (Figure 19b). A sudden decrease in confining pressure at this time, might have resulted in liberation of an aqueous phase which slowly accumulated in the top of the magma reservoir. As vapor pressure increased, alkalies would be preferentially partitioned into this aqueous phase, thus leaving a residual melt of peraluminous composition (Burnham, 1967). Subsequent rupturing of the magma chamber would result in rapid injection of the residual melt and volatile-rich aqueous phase towards the surface where it would crystallize rapidly to form dykes and sills of rhyodacite. The zones of brecciation and hydrothermal alteration associated with these intrusions probably represent escape channels for the gas-charged fluids (Norton and Cathles, 1973). Rifting continued after crystallization of the rhyodacite, with concommitant injection of partly crystallized magma of quartz monzonite composition along northwest-trending faults.

The mode of emplacement of the Bulkley Intrusions is difficult to determine. For the most part rocks adjacent to the intrusions have steep dips and there is some evidence for forceful intrusion and doming. This is particularly true for the Sibola Stock, where Hazelton Group strata are tilted to a vertical position along the eastern contact. By contrast, dykes of porphyritic quartz monzonite and rhyodacite within the Sibola Stock appear to have been passively injected along existing zones of weakness.

The depth to which the Sibola and Troitsa stocks are presently unroofed cannot be ascertained for certain. Although Buddington (1959) would classify such intrusions as mesozonal on the basis of contact metamorphism, discordant and concordant contacts and textural features within the intrusions, recent investigations of the Boulder Batholith (Tilling, 1974; Hamilton and Myers, 1974), and similar intrusions on Vancouver Island (Carson, 1973) would seem to indicate that such intrusions could have crystallized at depths less than two kilometers, perhaps crystallizing beneath a thin cover to their own volcanic ejecta (e.g., Hamilton, 1969).

Mt. Bolom Intrusions

The compositional trends of the Mt. Bolom Stock parallel those of the Bulkley Intrusions (e.g., Figure 18). However, the Mt. Bolom Stock is texturally distinct, having a granophyric groundmass and containing clots of earlier crystallized mafic minerals. Furthermore, there is a tendency toward peraluminous composition as evidenced by the presence of corundum in norm calculations. These features, and the fact that the stock intrudes and deforms volcanic rocks of the Mt. Baptiste Formation, suggest a high level of intrusion accompanied by rapid cooling and release of volatile constituents. The angular clots of mafic minerals and calcic plagioclase in these rocks may have originated by destruction of an early mafic border phase during periods of forceful injection of residual magma from depth.

5.4 Volcanic, Plutonic and Tectonic Relationships

Block faulting within and peripheral to the Kasalka Range may be of a volcano-tectonic origin, with the thick section of Kasalka Group volcanic rocks being preserved within a caldera-like structure. Rhine Ridge and Troitsa Lake could be the boundaries of this caldera, which is roughly circular in outline and has a mean diameter of approximately 30 kilometers (Figure 20). A northwest-trending fault appears to truncate the southwestern part of the caldera, where it apparently abuts against metamorphic rocks of the Coast Plutonic Complex. Although the structural picture is complex, radial and concentric faults can be recognized in the area peripheral to the proposed caldera (Figure 20).

Formation of the Tahtsa Lake caldera probably followed extrusion of felsic pyroclastic rocks of the Mt. Baptiste Formation, with crustal blocks collapsing into the vacated parts of an underlying magma chamber, probably in a manner similar to that described by Lambert (1974) for formation of the Bennett Lake caldera. Rhyodacite dykes, which parallel the north shore of Troitsa

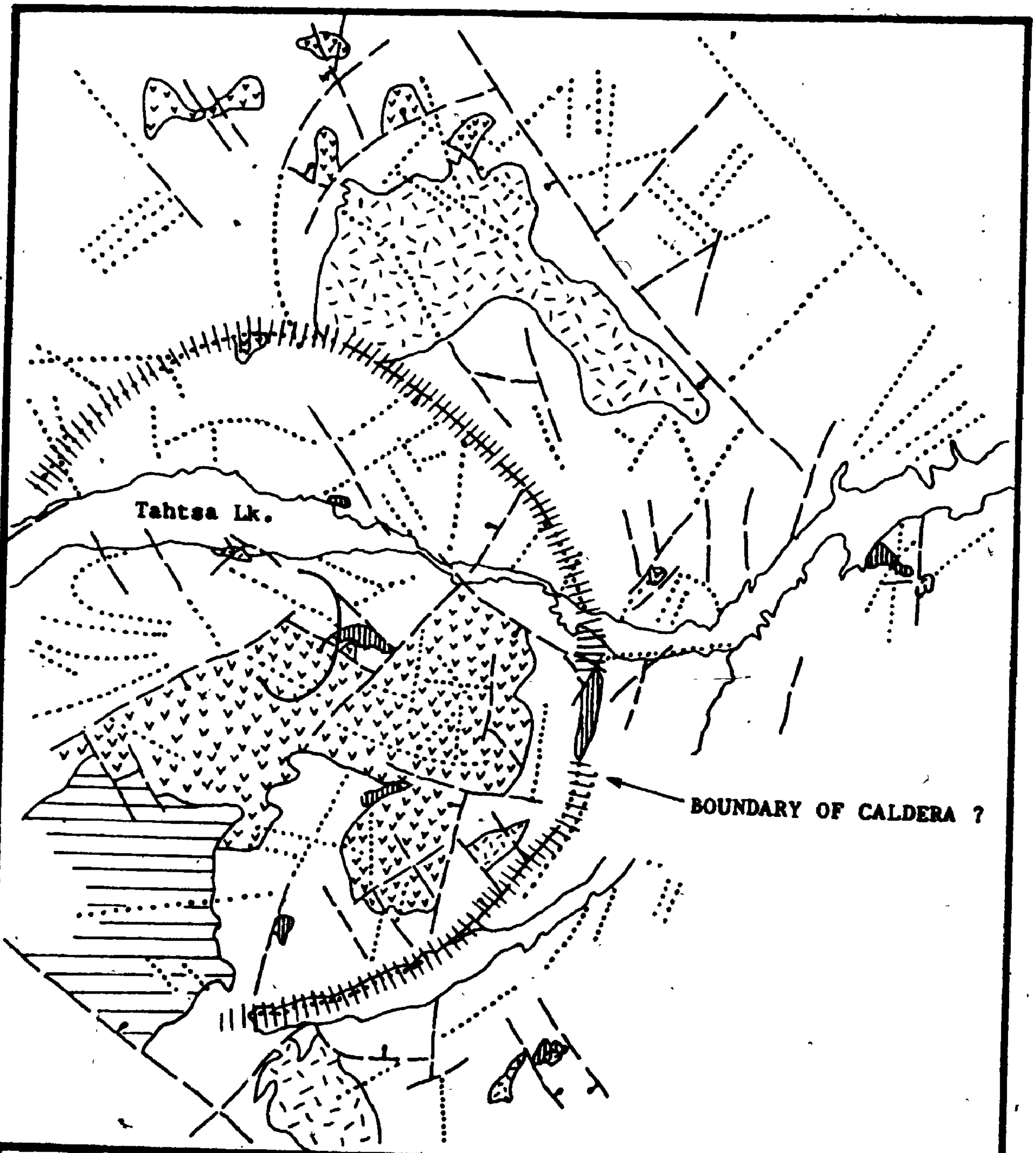


FIGURE 20. Distribution of Upper Cretaceous Volcanic and Plutonic Rocks and Approximate Location of the Tahtsa Lake Caldera

Mt. Bolom Stock

Kasalka Intrusions

Bulkley Intrusions

Kasalka Group

Major fault - ball on dowthrown blocks

Airphoto linear

Lake, are compositionally similar to the more felsic units of the Mt. Baptiste Formation, and may be subvolcanic feeders for the volcanic rocks. The dykes could be emplaced along ring fractures bounding collapsed blocks within the caldera. The proliferation of subvolcanic intrusions and pervasive propylitic alteration within the area of subsidence suggests that magmatic and hydrothermal activity accompanied and followed formation of the caldera.

Rocks of the Swing Peak Formation were deposited approximately 87 million years ago assuming that the K-Ar isotopic age determined for a flow near the base of the formation is correct (Appendix D). The fine-grained porphyritic dykes of the Kasalka Intrusions are probably the intrusive equivalents of these volcanic rocks, representing the roots of major eruptive centers. These intrusions are found both within, and peripheral to, the area of subsidence (Figure 20). The great volume of laharic debris preserved within the Kasalka Range may have been derived from volcanic cones bounding the area of subsidence and perhaps in part from the collapse of unstable caldera walls.

Diorite and quartz diorite stocks crop out in the area surrounding the Kasalka Range (Figure 20). Several of these intrusions, including the quartz diorite at Coles Creek and the diorite on Kasalka Butte, are elongate parallel to the inferred boundary of the Tahtsa Lake caldera suggesting they were emplaced along ring fractures. These intrusions are compositionally similar to latite-andesite flows and dykes within the Kasalka Range, and are probably comagmatic with these rocks, perhaps representing the more deeply exhumed parts of major volcanic centers.

The porphyritic granodiorite stocks at Coles Creek, Ox Lake and Huckleberry Mountain have K-Ar isotopic ages of around 82-83 million years (Appendix D). If these ages are correct, then it is suggested that emplacement of these intrusions did not take place until some 4 to 5 million years after deposition of the Swing Peak Formation. The Sibola and Troitsa stocks have K-Ar isotopic ages of around 75-76 million years. If these apparent ages are correct,then a time interval of approximately 11 to 12 million years separates the initial deposition of flows of the Swing Peak Formation and attainment of Ar retention temperatures for the Sibola and Troitsa Stocks. This time interval is consistent with the coarse-grained texture of the stocks which implies slow crystallization over a long period of time. By comparison, Moore, et.al., (1968) have shown that comagmatic volcanic and plutonic rocks in the Bingham district evolved over a time interval of about 7 million years duration, and those of the Boulder Batholith over 6 million years (Hamilton and Myers, 1974).

The rhyodacitic intrusions within the Sibola and Troitsa stocks have a similar composition to flows of the Bergette Formation, and these rocks may be cogmagmatic. It is interesting to note that rhyolitic flows in the Morice Lake area, approximately 30 km northwest of Tahtsa Lake, are reported to have K-Ar isotopic ages, c.a. 76 million years (Carter, 1974). This is very close to the age inferred for rhyodacitic intrusions within the Sibola Stock. The cylindrical shape of the porphyritic granodiorite stocks at Coles Creek, Ox Lake and Huckleberry Mountain, implies emplacement at the intersection of two or more fault zones. These faults could be related to formation of the Tahtsa Lake caldera. In fact, faults which are roughly radial to the proposed caldera do occur at Huckleberry Mountain and Coles Creek. However, the Ox Lake intrusion appears to be on a major northwest-trending fault. Northwest foliation of mafic minerals in the southeast arm of the Sibola Stock suggests that a northwest-trending fault may have controlled the localization of this intrusion as well.

If we assume that the models proposed earlier for the evolution of porphyritic rocks in the plutonic complexes of the Bulkley Intrusions are correct, then some mechanism is required to produce a relaxation of confining pressure during the waning stages of crystallization of these complexes. Such a mechanism could be of a regional tectonic nature, with the reduction of confining pressure caused by a change to an extensional tectonic regime. This is in part supported by the pronounced northwest orientation of late porphyritic dykes within the plutonic complexes and the fact that a similar trend is observed for younger dyke swarms in the area as a whole. Furthermore, the dykes parallel prominent joint and fracture directions which are also developed on a regional scale (e.g. Souther, 1970). Katz (1971) has described a similar change in tectonic environment related to evolution of the volcanic and plutonic rocks of the Andes of South America. Here, the volcanic arc marks the boundary between compression to the east and extension to the west.

The apparent age of the Mt. Bolom Stock has not yet been determined (sample submitted to the U.B.C. geochronology laboratory in 1975; results not yet available). Compositionally, the stock resembles the Bulkley Intrusions, and, therefore, a similar age would be expected. The stock intrudes and deforms Kasalka Group volcanic rocks within the core of the Tahtsa Lake caldera and probably represents a late stage of resurgent magmatism and central doming during evolution of the volcanic complex. Similar intrusive bodies occur within the Turkey Creek caldera of southeastern Arizona (Marjaniemi, 1969).

5.5 Formation of Porphyry Copper Occurrences

Porphyry copper occurrences are spatially associated with porphyritic phases of the Bulkley Intrusions. Clearly, the deposits are genetically related to emplacement of these intrusions as evidenced by the presence of intra and inter-mineral porphyritic dykes and zonation of alteration zones about the intrusions (Kirkham, 1971). On the basis of this association, it can be stated that formation of the porphyry copper occurrences occurred late in the volcanic-plutonic cycle, post-dating formation of major volcanic structures on the surface. This is particularly obvious at Coles Creek, where the porphyritic granodiorite actually intrudes volcanic rocks of the Mt. Baptiste formation (MacIntyre, 1974). Sillitoe (1974) has described similar relationships for recent volcano-plutonic centers which have been unroofed in the Central Andes of South America. Here, as elsewhere, (e.g., Richard and Courtright, 1960) formation of porphyry copper deposits has followed deposition of felsic volcanic rocks and caldera collapse. As mentioned earlier, emplacement of the porphyritic intrusions and therefore formation of porphyry copper occurrences may coincide with a change to an extensional tectonic regime during the final stages of evolution of a volcano-plutonic complex.

The genesis of the sulphide and alteration mineral zones that are characteristic of porphyry copper deposits has been discussed by various authors (e.g., Fournier, 1967; Neilsen, 1968; Rose, 1970; Sillitoe, 1974; Lowell and Guilbert, 1970). To date, two distinct models have been proposed. The first, referred to as the ortho-magmatic model, involves derivation of the hydrothermal fluids and metals directly from the magma. The metals are partitioned into a chloride-rich aqueous phase generated by retrograde boiling of residual melts during the final stages of crystallization of the porphyritic stocks (e.g., Holland, 1972). These fluids migrate outward from the source area, following zones of fracturing in surrounding rocks. Reduction of temperature and pressure away from the stocks produces the concentric arrangement of alteration and sulphide mineral zones (e.g., Rose, 1970). The second model pictures the intrusion as a heat source only, producing convective circulation of meteoric brines through fractured rocks enclosing the intrusion (e.g., Henley, 1973). The metals are leached from the country rocks and redeposited in areas with favorable physiochemical conditions. The author favors a combination of these two models, with an initial magmatic source for the metals and fluids, followed by mixing with meteoritic waters as they move outward into surrounding rocks. Isotopic and fluid inclusion studies (e.g. Field, 1966; Roedder, 1971; Sheppard et. al., 1971; Garlick and Epstein, 1966) support a magmatic source for the metals, but indicate a meteoric component in the hydrothermal fluids, particularly in the zones of intense sericitic alteration typically found peripheral to the intrusions. Rose (1970) suggests this zone represents the point of mixing of the magmatic and hydrothermal fluids. The close association of Cu/Mo ratios to intrusive rock type (e.g. Carter, 1974) further supports a magmatic origin for the metals contained in porphyry copper deposits.

The configuration of alteration and sulphide mineral zones in porphyry copper deposits is influenced by many different factors (Guilbert and Lowell, 1973).

Perhaps the most important of these with regard to the porphyry copper occurrences in the Tahtsa Lake area, is depth of exposure. For example, the porphyry deposits at Ox Lake and Huckleberry Mountain may be exposed at moderate depth with the upper parts of their hydrothermal systems removed by erosion. At this depth, circulation of fluids was presumably restricted to fractures and faults in hornfelsed country rock, thus restricting sulphide deposition and concentration to relatively small annular zones surrounding the stocks. By contrast, extensive zones of phyllic and argillic alteration occur at Coles Creek, primarily within downthrown fault block containing rhyolitic volcanic rocks of the Mt. Baptiste Formation (MacIntyre, 1974). Alteration assemblages within these rocks are the same as those found in modern geothermal systems suggesting that these rocks represent the near surface part of a porphyry copper system, (e.g. Sillitoe, 1974). Similar rocks may have overlain the Ox Lake and Huckleberry Mountain deposits prior to erosion.

5.6 Summary

If the interpretation of the geological, geochemical and geochronological data is correct, then evolution of Upper Cretaceous volcano-plutonic centers in the Tahtsa Lake area can be subdivided into four major stages (Figure 21). These are:

(1) Explosive volcanism and construction of volcanic plateau of predominantly

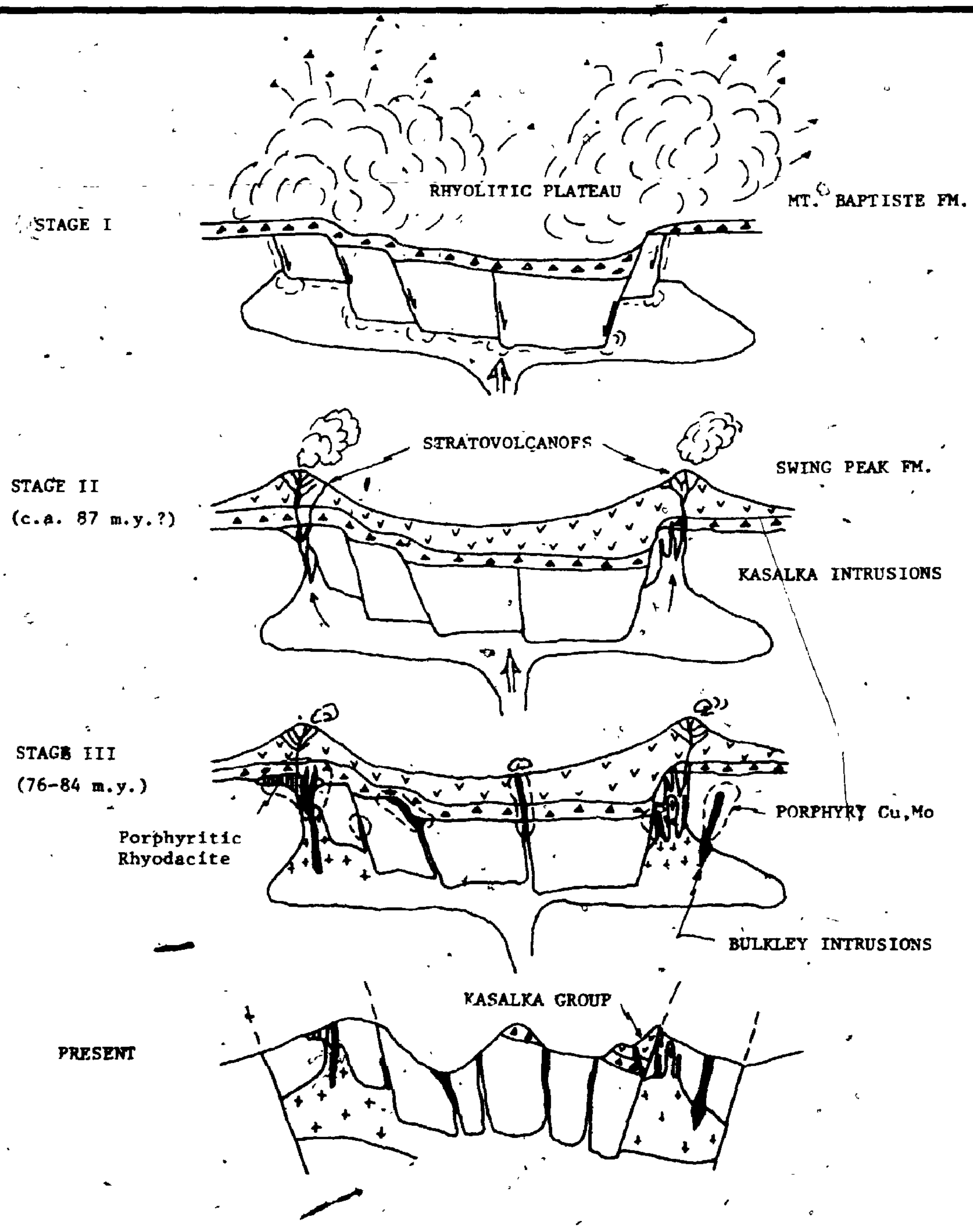


FIGURE 21. Possible stages in the evolution of volcanic and plutonic centers in the Tahtsa Lake area, and their relationship to formation of a major caldera structure. See text for explanation of stages.

rhyodacitic pyroclastic rocks. This may have been followed by formation of a major caldera in the Kasalka Range.

(2) Construction of andesitic strato-volcanoes within and peripheral to the caldera with deposition of laharic debris within the area of subsidence. Evolution of the strato-volcanoes was accompanied by intrusion and crystallization of andesitic necks and feeder dykes in the volcanic vents and stocks of dioritic to quartz dioritic composition at depth.

(3) Magma underlying the volcanic terrain crystallized slowly after cessation of volcanic activity to form coarse-grained equigranular bodies of granodiorite composition. During the final stages of crystallization, rifting occurred in response to a change to an extensional tectonic regime. This resulted in intrusion and possibly extrusion of gas-charged rhyolitic melt along fracture zones, followed by intrusion of porphyritic granodiorite and quartz monzonite dyke

swarms and stocks. Hydrothermal activity and formation of porphyry copper deposits occurred at this time.

(4) Extension and faulting continued after formation of the volcano-plutonic center, with injection of post mineral dykes of various compositions along northwest structural trends. The area was subsequently uplifted and unroofed during the Tertiary and Quaternary periods.

CHAPTER 6

EVOLUTION OF GEOLOGIC REGIMES IN THE TAHTSA LAKE AREA

6.1 General Statement

The rock units exposed in the Tahtsa Lake area represent three major geologic regimes spanning a time interval of approximately 125 million years. These are from oldest to most recent: (1) volcanic island arc regime, (2) successor basin regime, and (3) continental volcanic arc regime (Table 13, Figure 22). Although this thesis is concerned primarily with the latest of these, all three are important in understanding the evolution of the Tahtsa Lake area. Furthermore, the geologic record is probably more complete in this area than most parts of West Central British Columbia, and as such, the area provides important clues to the sequence of events in evolution of both the Nechako Trough and the Coast Plutonic Complex.

6.2 Volcanic Island Arc Regime

The oldest rocks of the Tahtsa Lake area are part of a volcanic island arc regime present in the western part of the Canadian Cordillera from Triassic to earliest Cretaceous time (Douglas et.al., 1969; Wheeler, et. al., 1972).. The stratigraphic and lithologic features of the Jurassic rocks exposed in the Tahtsa Lake area suggest a trend from explosive submarine to subaerial volcanism

TABLE 13

SUMMARY OF GEOLOGIC REGIMES, TAHTSA LAKE AREA

REGIME	TIME INTERVAL	ENVIRONMENT OF DEPOSITION	EXTENT AND THICKNESS	MAJOR ROCK UNITS	RELATED MINERAL DEPOSITS
VOLCANIC ISLAND ARC	L-M. Jurassic 160 - 190 m.y.	Shallow water marine to nearshore subaerial. Close to volcanic centers.	Entire area 3.5 km	Hazelton Group -andesitic to rhyolitic volcanic rocks. -marine sedimentary rocks.	Strata bound Massive sulphide Vein deposits in volcanic rocks.
		DEFORMATION, UPLIFT AND EROSION			
SUCCESSOR BASIN REGIME	L. Cretaceous (Albian) 105-112 m.y. ?	Initially continental changing to shallow water inland marine trough. Gradual subsidence with time.	Limited to Tahtsa and Kasalka Range? 1.5 km in center of trough.	Skeena Group -basaltic flows -marine clastic sedimentary rocks.	Zones of hydrothermal alteration related to volcanism?
		DEFORMATION, UPLIFT AND PENEPLANATION			
CONTINENTAL VOLCANIC ARC REGIME	U. Cretaceous 105 - 77 m.y.	Erosion surface with red bed deposits. Explosive volcanism, and construction of rhyolitic volcanic plateau, with caldera subsidence. Construction of stratavolcanoes. NW rifting and crustal extension	Entire area? Up to 1.5 km in Kasalka Range.	Kasalka Group Kasalka, Bulkley and Mt. Bolom Intrusions. NW dyke swarms.	Porphyry copper deposits. Pb-Zn-Ag veins.
	EOCENE c.a. 50 m.y.	similar to above?	Western part of Tahtsa Range	Coast and Nanika Intrusions	
		BLOCKFAULTING, UPLIFT AND EROSION			

in early to mid Jurassic time, succeeded by shallow water marine sedimentation and perhaps followed by another major volcanic episode in the late Jurassic. Marine transgression was preceded by a relatively short interval of subaerial felsic volcanism as represented by rhyolitic fragmental rocks in this part of the section. The coarse, fragmental nature of the volcanic rocks, which locally contain sedimentary horizons, suggests that the Tahtsa Lake area was in close proximity to an active volcanic arc throughout most of the Jurassic. The volcanic centers were probably located along the Skeena Arch which is just north of the study area. At the close of the Jurassic, the Tahtsa Lake area was subjected to regional compression, accompanied by folding, uplift and erosion.

6.3 Successor Basin Regime

In Lower Cretaceous time, successor basins and troughs were superimposed on much of the Nechako Trough (Wheeler et.al., 1972). In the Tahtsa Lake area, rocks of the Skeena Group are considered part of this regime. In this area, the first stage in successor basin evolution appears to have been rifting and extrusion of basaltic flows. With continued subsidence, probably in part tectonically controlled, an inland marine trough evolved and was slowly filled with debris derived from uplifted metamorphic rocks to the west (Figure 22). In late Albian time, the area was once again deformed and uplifted with subsequent peneplanation. By latest Albian time, the area

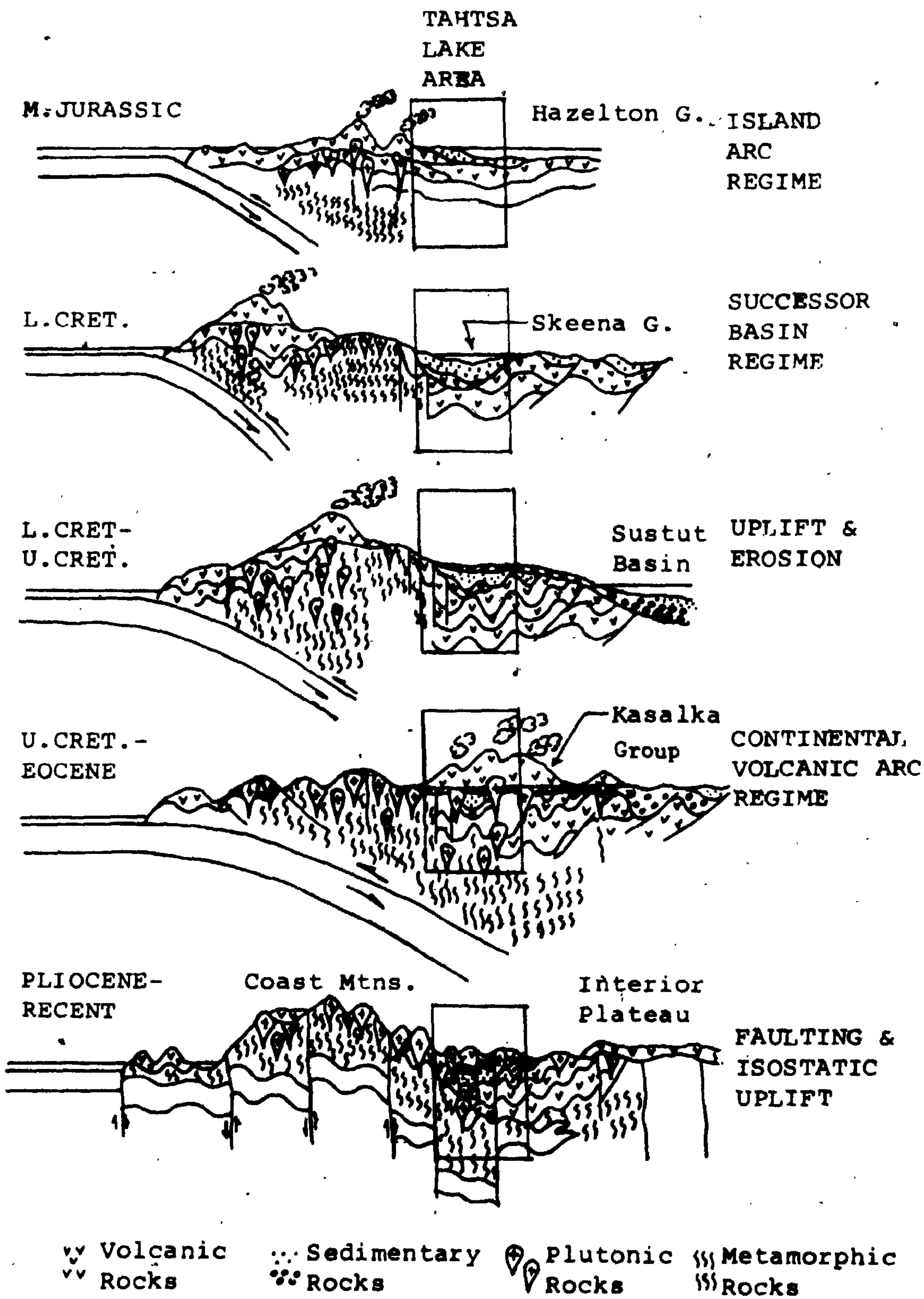


FIGURE 22. Geologic evolution of the Tahtsa Lake area, middle Jurassic to present.

was essentially a plateau covered by a thin cover of oxidized gravels and sands.

6.4 Continental Volcanic Arc Regime

In earliest Upper Cretaceous time, the Tahtsa Lake area became part of a continental volcanic arc regime, with deposition of Kasalka Group volcanic rocks and intrusion of related plutonic rocks. During the late stages of this activity, the area became part of an extensional tectonic regime with block faulting and intrusion of magma along northwest-trending rifts. Deep erosion of the volcanic cover and unroofing of plutonic rocks, preceded emplacement of the Nanika and Coast Intrusions, c.a. 50 m.y. Any volcanic cover associated with these intrusions has since been removed by erosion. In Pliocene time, block-faulting and uplift related to evolution of the Coast Mountains to the west, further modified the tectonic framework of the area.

6.5 Plate Tectonic Models

The geological evolution of the Tahtsa Lake area can be understood in terms of the plate tectonic model proposed by Monger, et.al., (1972) for evolution of the Pacific Orogen. This model involves island arc volcanism above eastward dipping subduction zones at least until the close of the Jurassic. At this time, subduction zones may have stepped oceanward with subsequent consolidation of the leading edge of continental plate and formation of successor basins inland (Wheeler et al., 1972). Continental volcanic arcs formed above the subduction zone and migrated eastward reaching the Tahtsa Lake area by mid Cretaceous. The volcanic arcs were preceded by deformation, uplift and erosion of older rocks, and deposition of red bed deposits on newly formed plateaus. Overriding of the continental plate resulted in uplift and unroofing of plutonic and metamorphic roots of the older volcanic arcs along the continental margin. The superposition of late Cretaceous and early Tertiary plutonic rocks in the Tahtsa Lake area may reflect a change to oblique subduction in the Tertiary (Coney, 1972). By Oligocene time, subduction had ceased with tectonic activity being confined to movements on transcurrent faults and isostatic uplift of the Coast Plutonic Complex.

6.6 Origin of Calc Alkaline Magmas

The Upper Cretaceous rocks of the Tahtsa Lake area are typical of calc-alkaline volcano-plutonic arcs of the continental margins of North and South America. The origin of the magmas, which produce these igneous terrains, is still a subject of considerable debate. Perhaps the most accepted theory is that magma generation is somehow related to processes of plate subduction (e.g. Gilluly, 1971). The superposition of magmatic activity above inclined seismic zones, and parallelism of volcano-plutonic arcs with deep sea trenches and mid-ocean ridges, are clearly established for most, although not all active volcanic arcs (Carmichael et.al., 1974).

Based on the experimental work of Green and Ringwood (1968) calc-alkaline magmas could be derived by partial melting of anhydrous quartz eclogite at depths in excess of 100 kilometers. The eclogites may be derived by recrystallization and dehydration of subducted oceanic lithosphere with or without deeply buried lower crustal rocks (Brown and Fyfe, 1970). The model favored in this study involves tectonic thickening of an overriding continental plate and partial melting of the lower crust above a subduction zone. Liquids derived by metamorphism and dehydration of the subducted oceanic plate may have provided energy and water to accelerate this process.

The mechanism of magma accumulation and emplacement have been discussed by various authors (e.g. Fyfe, 1970, 1973). The most acceptable model in terms of fluid dynamics is one in which magma is generated at depth and rises slowly through the crust as gigantic tadpole-shaped masses. The relatively light magma pushes aside denser crustal rocks and may begin to spread laterally as it approaches the surface (Carson, 1969; Hamilton and Myers, 1974). These relationships are well-exposed in the Coast Plutonic Complex where hundreds of tadpole-shaped plutons appear to be frozen at various crustal levels (Hutchison,1970). Many of these plutons are rooted in migmatite zones interpreted to represent areas of partial crustal fusion (Bateman and Eaton, 1967). It is possible that such a zone underlies the Tahtsa Lake area at depth and was the source of the Upper Cretaceous volcanic and plutonic rocks.

CHAPTER 7

CONCLUSIONS

(1) Volcanic rocks of earliest Upper Cretaceous age overlie older rocks in the Tahtsa Lake area with angular discordance. These volcanic rocks are preserved in a major structural depression in the Kasalka Range. Plutonic rocks of a comparable age have been unroofed in the area peripheral to this depression.

(2) Calc-alkaline volcanic and plutonic rocks of Upper Cretaceous age are probably part of a major volcano-plutonic complex which evolved over a time span of approximately 11 million years. Evolution of this complex began with explosive rhyolitic volcanism followed by caldera collapse and finally construction of stravolcanoes within and peripheral to the area of subsidence. This was followed by slow crystallization of granodioritic magma below the volcanic terrain.

A change to an extensional tectonic regime during the final stages of crystallization triggered emplacement of late stage differentiates as northwest-trending porphyritic dyke swarms. Porphyry copper occurrences were formed at this time.

(3) The rocks present in the Tahtsa Lake area reflect a change from an island arc regime in the Jurassic, to a successor basin regime in the Lower Cretaceous, to a continental volcanic arc regime in the late

Cretaceous to early Tertiary. This change suggests an eastward migration of tectonic and igneous activity during evolution of the Pacific Orogen. The configuration of the Western Cordillera during late Cretaceous time was essentially the same as that of the present day Andes of South America, with volcano-plutonic arcs situated above an eastward dipping subduction zone.

CHAPTER 8

RECOMMENDATIONS

The Tahtsa Lake area provides a rare opportunity to study the nature of Upper Cretaceous volcanism and plutonism in the Western Cordillera. Therefore, it is recommended that the present study be considered to be of a preliminary nature, setting a foundation for more detailed examination of the area in the future. Specifically, more isotopic age determinations are needed to better define the apparent relationships between the volcanic and plutonic rocks. More data on the chemical composition of these rocks would also be useful, particularly trace element and isotopic analyses. Finally, in view of the discoveries in the Tahtsa Lake area, it is recommended that other areas known to contain volcanic rocks of similar age and composition be investigated to construct a more complete picture of Upper Cretaceous volcanic activity.

APPENDICES

A Sample Descriptions

B Analytical Procedures

C Kasalka Group Type Sections

D K-Ar Analytical Data

APPENDIX A SAMPLE DESCRIPTIONS

Samples with thin sections underlined. Abbreviations used: PL=plagioclase; KF=K-feldspar; QZ=quartz; PX=augite; HB=hornblende; BT=biotite; MS=muscovite; CH=chlorite; EP=epidote; CB=carbonate mineral; CL=clay; RX=rock; XL=crystal; GL=devitrified glass; HM=hematite; MT=magnetite; LM=limonite; PY=pyrite; p=phenocryst; g=groundmass; f=fragment; a=alteration mineral; o=oxidation product; tr=trace to absent.

Samples in Group	General Characteristics of Group	Estimated Modal Composition				Remarks
HAZELTON GROUP 1a.						
D85,152,153,213 M60,66,69,88,89, 90,99	Aphanitic dark green subporphyritic andesite, basalt and XL tuff. Pilotaxitic groundmass. Chlorite clots common. Mafic minerals altered to CH and EP.	PLp:	0-10	CHa:	5-10	
		PLg:	40-60	EPa:	1-5	
		QZg:	2-5	MTg:	1-2	
		CHg:	5-10			
		CLa:	1-5			
D82,83,84,86,89, 90,178,179,218, 243 M70,83,87,90,98, 100,101,112,159, 187,232	Red, green and grey lithic lapilli-tuff. Up to 20% fragments of andesite, tuff. Aphanitic siliceous matrix.	XLf:	1-5	CBa:	1-5	D82,83,89,218, M30 - eutaxitic texture D90,243 - reworked
		RXf:	15-20	EPa:	tr	
		GLf:	1-5	CHa:	tr	
		QZg:	30-40	HMo:	tr	
		PLg:	5-25			
		CLa:	1-5			
D87,88	Fine-grained red ash and crystal tuff. Graded bedding, thin bedded. Included fragments mainly PL and QZ.	XLf:	20-30	PLg:	5-10	
		RXf:	15-20	CBa:	tr	
		GLf:	1-2	CLa:	tr	
		QZg:	10-20	CHa:	tr	
D192,216,237 M16,58,85,86,186	Red, purple and green subporphyritic tuffaceous andesite. Few XL and RX fragments.	PLp:	5-25	MTg:	10-15	
		PLg:	40-50	CBa:	tr	
		QZg:	1-5	HMo:	1-2	
		KFg:	5-10			
D27,29,33,34	Purple to mauve tuff-breccia, agglomerate. Angular to subangular blocks and lapilli of porphyritic andesite and red tuff. Fine-grained matrix with Qz and PL crystal fragments.	XLf:	10-15	CLg:	tr	
		RXf:	40-50	MTg:	tr	
		PLg:	10-15	LMo:	tr	
		QZg:	10-15	HMo:	tr	
		CHg:	1-5			

HAZELTON GROUP (CONT'D)

1a.						
D30,31,32,181,182, 233,234,235 M56,84	Porphyritic pink, red, mauve and grey augite andesite. Euhedral andesine phenocrysts. Pilotaxitic groundmass with inersertal KF, QZ and iron oxide. Propylitic alteration common.	PLp: PXp: PLg: KFg: QZg: MTg:	15-40 1-3 20-60 5-20 1-5 2-3	CBa: CHa: HMo:	1-2 tr 1-5	
1b.						
D26,36,37,38,199, 209 M59	Aphanitic dark grey, mauve and light green dacite. Few .5mm BT flakes, 1mm oriented PL laths. Pilotaxitic groundmass with intersertal microcrystalline QZ, PL, and KF.	PLp: BTp: PLg: QZg: KFg: MTg:	tr-1 tr-1 50-60 25-30 10-15 2-3	HMo:	1-2	
D68,151,239 M22,31	Light grey moderately welded lithic lapilli-tuff. RX fragments mainly andesite, dacite and rhyolite. Shards of devitrified glass common.	RXf: GLf: XLf: QZg: PLg:	10-35 1-15 1-5 40-50 10-15	CHa: CBa: HMo:	1-5 1-2 tr	D239, M55 - EP alteration M22 - Pyritic
D66,67,154,155, M131,248	Dark grey siliceous lithic tuff. Remnant vitroclastic texture. XL fragments mainly QZ, PL; RX fragments mainly andesite. Microcrystalline QZ-MS groundmass.	XLf: RXf: GLf: HMg: QZg:	5-10 10-15 1-5 1-3 30-40	MSg: CLa:	5-10 1-5	D154,155;M248 - biotite hornfels
D189,190,196,240 M52,54,55	Mottled grey, green, mauve and white rhyolitic to dacitic tuff and cherty tuff. In places partly welded.	XLf: RXf: QZg: CHg:	tr 1-5 60-70 5-10	CBg:	1-5	
D209, M17,18,21,31,35, 53	Light green, grey and white massive and banded rhyolite and dacite. Microgranular groundmass of QZ and KF.	QZg: KFg: PLg:	60-70 25-30 5-10	HMo:	tr	M31 - Hornfels

HAZELTON GROUP (CONT'D)

1c.						
D241 M63,68,91,94,96	Banded and mottled grey and white chert. Commonly tuffaceous. Dark grey clay rich inclusions.	QZg: CLg: CHg:	80-90 1-5 tr	PYg:	tr	
D229,232,254 M20,61,65,129,130, 136,139,239	Thin bedded black to dark grey siliceous argillite and argillaceous siltstone. Microcrystalline QZ-MS groundmass. Locally tuffaceous.	XLf: RXf: QZg: MSg:	tr tr 40-70 20-40	CLg: CHg: CBa:	5-10 1-5 tr	
D53,53A,55,56,57, 58,65,71,148,150, 208,210,211 M47,51,64,65,135	Poorly sorted dark to light grey volcanic sandstone. Subrounded clasts of chert, siliceous argillite, rhyolite, andesite, and tuff, .5-2mm in diameter. Commonly tuffaceous.	QZf: PLf: RXf: CLg: CHg:	10-15 15-35 5-35 5-15 1-5	CBg:	1-10	
SKEENA GROUP						
2a.						
D1,3,5,6,7,12A,13, 25,46,47,106,117 M139,183,205	Light grey to greenish grey amygdaloidal, subporphyritic basalt. Light colour due to leaching. CH, QZ, and CB filled amygdules to 10% Intersertal CB in pilotaxitic groundmass.	PLp: PLg: CBg: CHa: MTg:	1-5 60-70 5-10 1-5 2-3	QZa: HMo:	tr tr	D1,5,7,160,M139 - pyritic D46,92,106 - Non porphyritic D3,6,12A,117 - Intensely altered
D154,160,162,167, 209,210 M185	Dark grey to green amygdaloidal, porphyritic basalt. Euhedral PL phenocrysts, 1-1.5mm. CH clots common. Both CH and CB filled amygdules present.	PLp: CHg: PLg: CBg: CLa:	25-45 10-15 5-20 tr tr-15	MTg:	2-3	D162, M185 - oxidized
D8,10,12,15,69,70, 116,118,149,159A, 161,163, M23,50,156,159,204, 206	Dark green basalt. Few amygdules, PL phenocrysts. Chlorite clots common	PLp: CHg: CBg: MTg: EPa:	1-5 10-15 5-10 2-3 tr-1			D69 - Hematitic M159 - Hornfelsed D116,213,M156 - Trachytic texture

SKEENA GROUP (CONT'D)

2b.

D18,42A,43,51,77A, 79,93,94,96,97,98, 100,103,104,108, 109,114,115,166, 174,206,220,224, 246 M1,9,12,29,110,111, 141,161,163,181, 182,226,234,240	Buff to medium grey sandstone or lithic wacke. Moderate to well-sorted. Grains of metamorphic and plutonic rocks plus QZ,PL,KF,BT and MS. Grains rounded to subangular. Silica cement. Fe-rich concretions common.	QZf: 20-30 PLF: 10-15 MSf: 1-2 BTf: tr KFf: 1-5 RXf: 15-35 CLg: 5-10 CBg: 0-5 QZg: 5-10	D97-109;M110 -- sericitic alter. M112 - hornflesed
D95,115,167,223	Medium to light grey siltstone. Finer-grained equivalent of above.	same as above	
D15,22,78,145,205 251,253 M10,180A	Dark grey argillaceous sandstone or lithic wacke. Lenses and stringers of argillaceous material. Clay-rich matrix.	QZf: 15-20 PLf: 1-2 MSf: 5-10 CLg: 30-40 CBg: 1-2 QZg: tr	
D77,214 M26,140,180	Dark grey to black shale. Very fine laminations of siltstone. Abundant MS flakes expecially on cleavage planes.	QZf: 10-15 PLf: tr MSf: 10-15 CLg: 10-15	

KASALKA GROUP

Basal Conglomerate

3a.

D144,225,258 M179,242	Reddish brown to grey pebble conglomerate. Poorly-sorted, rounded to subangular clasts of Hazelton Group volcanic rocks in coarse sandy matrix. Moderately to poorly indurated with silica Fe-oxide cement. Sandy lenses common.	RXf: 60-70 PLg: 5-10 QZg: 25-30 KFg: 1-5 CLg: 5-10 LMo: 1-2 HMo: 1-2	M179 - Galena in matrix

KASALKA GROUP (CONT'D)

3b. Mt. Baptiste Formation

D135,139,140,168, 245 M211,212	Medium grey porphyritic BT-HB dacite.	PLp:	25-40	MSg:	1-5
	Euhedral and broken PL, QZ, BT, and HB phenocrysts, 0.5-4 mm.	QZp:	2-5	CHa:	1-2
		BTp:	2-4	EPa:	1-2
	Microgranular to cryptocrystalline QZ-KF-PL groundmass.	HBp:	2-4	HMo:	0-tr
		PLg:	20-30	RXf:	0-2
	Occasional inclusions of dacite and andesite rock fragments.	QZg:	25-30	XLf:	0-2
		KFg:	15-25		
	CH and EP alteration common.	MTg:	1-2		
D248A M197	Medium grey to greenish grey HB-PX latite-andesite.	PLp:	15-40	CHa:	1-2
		HBp:	5-10	EPa:	1-2
	Euhedral tabular PL, HB, and PX phenocrysts, 0.5-1.5 mm.	PXp:	1-5	HMo:	1-2
		PLg:	20-45		
	Pilotaxitic groundmass with minor intersertal QZ and KF.	QZg:	4-10		
		KFg:	5-15		
	Intense CH-EP-MT alteration of mafic minerals.	MTg:	1-2		
M195	Light grey to cream aphanitic flow, banded rhyodacite.	PLp:	tr	QZg:	25-30
		QZp:	tr	PLg:	45-50
	Microgranular intergrowth of QZ, KF, and PL.	BTp:	tr	KFg:	25-30
		XLf:	tr	MSg:	5-10
	Mafic minerals rarely present.	RXf:	tr	HBg:	tr
D136,137,169,170, 171,172,173 M146,213	Light grey to reddish brown XL lithic tuff.	XLf:	25-30		
		RXf:	5-10		
	Angular fragments of QZ, PL, BT, HB and volcanic RF less than 2 mm. in diam.	QZg:	30-40		
		PLg:	5-10		
	Microcrystalline siliceous groundmass.	KFg:	5-10		
	Partly to moderately-welded (eutaxitic)	CHa:	1-2		
	Graded bedding common.	HMo:	1-2		
D247 M196	Light to medium grey lithic lapilli-tuff.	RXf:	25-40	CHa:	0-2
	Poorly sorted, non to partly welded.	XLf:	10-15	EPa:	0-2
	Angular to subrounded RF of various rock types, up to 10 mm. in diam.	QZg:	25-30	HMo:	tr
		PLg:	5-10	CLa:	1-5
	Occasional bomb or block.	KFg:	5-10		
	Micro to cryptocrystalline groundmass.				

KASALKA GROUP (CONT'D)

3c. Swing Peak Formation

D39,40,41,120,122, 124,131,183,184, 188,259,260 M164,165,176,200, 201,214,216,217, 218,219,221,225	Fine to medium-grained green, grey and reddish brown porphyritic latite-and-esite to dacite.	PLp:	10-40	MTg:	2-3	D39,40,120,122,
	Euhedral tabular andesine, green HB,	HBp:	2-10	CHa:	1-2	124,1 6; M200,
	augite + biotite phenocrysts, 1.5-4 mm.	PXp:	1-5	CBa:	tr-1	214,216,217,218,
	Pilotaxitic to microgranular groundmass.	QZp:	tr	HMo:	tr-2	219,221 - Intense alteration
	Pervasive chlorite, clay, carbonate, and iron oxide alteration common.	BTp:	tr	EPa:	0-2	M221 - Member C
		PLg:	20-30			all other samples are Member A
		KFg:	5-10			
		QZg:	1-2			
D123	Reddish brown to greenish grey lahar.	RXf:	50-60	CHa:	1-2	
	Latite-andesite,dacite, diorite rock fragments in muddy matrix.	PLg:	5-10	HMo:	1-2	
	Pervasive CH and Fe oxide alteration.	QZg:	5-10	XLf:	5-10	
		CLg:	20-30			
3d. Bergette Formation						
M124,127,178,184	White to pinkish grey aphanitic rhyo-dacite.	PLp:	1-5			M124 - 1-2% PY
	Few 1 mm. PL phenocrysts.	QZg:	60-70			
	Microgranular groundmass of inter-locking QZ enclosing randomly oriented PL laths.	PLg:	20-30			
	Flow banding common.	KFg:	5-10			
		MSg:	1-5			
M243	White to pinkish grey aphanitic rhyo dacite.	QZf:	10-15	KFg:	1-5	
	Abundant .1 to .5 mm. angular quartz PL and BT crystal fragments.	PLf:	5-10	EPa:	1-5	
	Micro to cryptocrystalline QZ rich matrix.	BTf:	1-2			
		QZg:	60-70			
		PLg:	5-10			

KASALKA INTRUSIONS

4a.

NE25	Medium grey to cream porphyritic BT-HB dacite.	PLp:	20-30	QZg:	15-20	*Abundant dissem. PY
	Euhedral and broken PL, QZ, BT, HB pheno-crysts. QZ "eyes" common.	QZp:	3-5	KFg:	15-20	
	Microgranular QZ-KF groundmass.	BTp:	1-5	MTg:	1-2	
		HBp:	1-3	MSa:	1-15	
		PLg:	15-20	CLa:	0-5	

KASALKA INTRUSIONS (CONT'D)

4b.						
D2,17,35,44,45,48,	Fine-grained green to grey HB-PX latite-	PLp:	15-45	QZg:	1-5	D44,80 - unaltered
49,61,71,72,73,74.	andesite.	HBp:	5-10	CHa:	1-5	M197 - Pyritic
75,80,81,99,166,	Euhedral zoned PL, PX, HB phenocrysts,	PXp:	1-5	CBa:	1-5	D251,M203,208 - EP
176,251,256	altered to CL, CB and CH.	QZp:	tr	QZa:	tr	alteration
M38,67,168,175,177,	Mafic minerals oxidized to HM.	BTp:	tr	HMa:	1-5	M168 - Intense
188,189,197,203,	Pilotaxitic to microgranular	PLg:	20-30	EPa:	tr	sericitic alter.
207,208.	groundmass.	KFg:	10-15	CLa:	1-5	
4c.						
D105,227,228,249,	Dark green to yellowish grey BT-PX-HB	PLg:	50-60	EPa:	tr	D253,M123 - Py-
250,252,253A	diorite.	HBg:	5-10	CHa:	1-10	ritic
M62,123,162,229,	Fine to medium-grained subporphyritic	PXg:	1-5	CBa:	1-5	
230,231,249	to equigranular texture.	BTg:	5-15	HMo:	tr	
	Pervasive CH, CB, KF alteration.	MTg:	1-2			
	Intersertal PX, HB, partly to completely	KFg:	1-2			
	altered to BT and CH.	QZg:	1-2			
	Minor interstitial QZ and KF.	CLa:	1-5			

BULKLEY INTRUSIONS

5a.						
D101,102,177A,255	Medium to dark grey HB-BT quartz diorite.	QZg:	15-28	MTg:	1-3	M112-138 - Sibola
M112,122,132,133,	Equigranular to subporphyritic texture.	KFg:	5-12	CHa:	0-1	Stock
134,137,138	Interstitial QZ and KF.	PLg:	45-58	MSa:	tr	D255 - Mt. Baptiste
BZ14	CH alteration of BT common.	BTg:	5-19			Stock
		HBg:	1-8			BZ-14 - Coles Crk.
5b.						
D107,132,156,157,	Pink to medium grey HB-BT granodiorite	QZg:	20-30			
158	Equigranular to subporphyritic texture.	KFg:	18-25			
M71,74,75,76A,77,	Interstitial QZ, KF, and PL.	PLg:	42-50			
81,95,104,107,	Minor CH after BT.	BTg:	2-4			
111,113,118,120,		HBg:	2-8			
120A,121,236,238		MTg:	1-2			
HB 72-11		CHa:	tr			
WC 9-93		MSa:	tr			
WC 7-47						

BULKLEY INTRUSIONS (CONT'D)

Samples	Description	Mineral	%	Mineral	%	Notes
5c.						
D111,204,219,226	Medium to dark grey porphyritic HB-BT	PLp:	25-45	MSa:	0-5	OL = Ox Lake
M40,105,143,158,246, 247	granodiorite.	BTp:	2-10	KFa:	0-5	HB = Huckleberry
OL12-795;18-984;32-166	Euhedral PL, BT, and HB phenocrysts to 8 mm. in diameter.	HBp:	1-8	CLa:	tr-2	CC = Coles Creek
HB72-5-460;72-11-473; 73-1-493;73-7-430; 73-16-991	QZ phenocrysts rare.	QZp:	0-2	CHa:	0-2	
CC-3-571	Microgranular QZ-KF- PL groundmass.	PLg:	8-12	EPa:	0-tr	
		QZg:	20-30	PYa:	tr-5	
		KFg:	15-20			
		MTg:	1-2			
5d.						
M79,106,119,127	White to cream porphyritic to aphanitic rhyodacite.	QZp:	2-15	PYg:	2-3	WC = Whiting Crk.
WC11-107	Bipyramidal QZ "eyes" characteristic.	PLp:	2-3			
	Sparse PL phenocrysts to 1 mm. in diam.	QZg:	60-65			
	Microgranular QZ-MS-KF groundmass.	KFg:	10-15			
	Disseminated PY cubes common.	MSg:	5-10			
	PL mainly albite.	PLg:	5-20			
		MTg:	tr			
5e.						
D9,11A,14,20,28,52, 52A,54,113,187,194,	Pinkish grey porphyritic HB-BT quartz monzonite.	PLp:	25-45	MTg:	1-2	
M41,48,72,78,82,82B, 90,102,103,109,114,	Euhedral PL, BT, HB, and QZ phenocrysts.	BTp:	4-8	CHa:	0-2	
115,116,128,128A, 142,228,245	Microgranular QZ-KF-PL groundmass.	HBp:	4-8	CLa:	0-1	
WC8-300;WC8-350		QZp:	2-5	CBa:	tr	
		PLg:	5-10	EPa:	0-1	
		QZg:	25-35	MSa:	tr-2	
		KFg:	20-25			

MT. BOLOM INTRUSIONS

Samples	Description	Mineral	%	Mineral	%	Notes
6						
D197,198,200,201,202	Fine to medium grained, pink to pinkish grey porphyritic granophyre.	PLp:	20-30	CHa:	tr-1	M191 - Badly weathered
M191,192,193,194,199	Euhedral oligoclase, BT, HB, phenocrysts to 5 mm. in diam.	BTp:	5-10	EPa:	0-tr	M193 - HB rich
	Clusters of PL, BT, and HB and mafic inclusions characteristic.	HBo:	1-5	CBa:	0-tr	D197-M199 from Mt. Bolom Stock
	Interlocking PL laths with interstitial micrographic intergrowth of KF and QZ in groundmass.	PLg:	40-50	CLa:	tr	
		KFg:	10-20			
		QZg:	15-25			
		MTg:	1-2			

MT. BOLOM INTRUSIONS (CONT'D)

6						
D64,92	Finer-grained equivalents of above.	PLp:	10-15	HMo:	0-2	M5,19,222 -
M2,3,4,5,6,8,11,14,	HB usually altered to CH or absent.	BTp:	1-2	MSa:	0-5	Unaltered
19,28,32,41,43,220,		KFg:	15-20	CHa	0-tr	
222		PLg:	40-50	CBa:	0-tr	
		QZg:	15-25			

DYKES

7a.						
D186,188,191,193,	Light pinkish grey to cream rhyodacite.	QZp:	10-15	KFg:	10-15	Could be ring dyke
195,207	Bipyramidal, rounded and embayed QZ,	PLp:	5-10	PLg:	10-15	related to Mt.
	broken PL and euhedral Kf with minor	KFp:	0-5	MSg:	10-15	Baptiste Formation
	BT phenocrysts.	BTp:	1-5	CLa:	tr-5	
	Microgranular QZ-KF-PL-MS groundmass.	QZg:	40-50	CBa:	0-tr	
	PL mainly albite.					
7b.						
D58,60,128,129,141,	Fine-grained dark to medium grey	PLp:	1-5	CLa:	1-2	
142,143,146,185,	andesite.	HBp:	1-5	CHa:	2-5	
244	Sparsely porhyritic with few PL and	QZg:	5-10	EPa:	0-1	
M7,27,37,39,80,93,	HB phenocrysts.	KFg:	1-2	CBa:	1-5	
117,145,166,168,	Locally amygdaloidal.	PLg:	40-60	HMo:	1-2	
170,172,173,174,	Very susceptible to weathering and	PXg:	2-5	LMo:	0-2	
198,223,244	oxidation - mafics rarely fresh.	MTg:	2-3			
7c.						
D180,221,245,248,	Fine-grained dark grey basalt.	PLg:	50-70	QZg:	tr	
261	Usually vesicular or amygdaloidal.	PXg:	10-15	CHa:	1-5	
M34,36	Rarely fresh, generally intensely	HBg:	5-10	LMo:	1-10	
	oxidized.	BTg:	2-3	HMo:	1-5	
D221	Dark grey lamprophyre (Kersantite ?)	PLg:	30-50	CHa:	5-10	
M108	Abundant BT and MT	BTg:	15-30	CLa:	tr-2	
	Generally quite fresh.	PXg:	5-10	CBa:	1-2	

COAST INTRUSIONS

8						
M13,30,42,153,155,	Medium-grained, medium to dark grey	PLg:	50-60	KFg:	5-15	M153- Mafic-rich
233	equigranular quartz diorite.	HBg:	10-20	MTg:	1-5	
	Interlocking, tabular zoned PL,	BTg:	4-10	PXg:	tr	
	anhedral BT and HB with interstitial	QZg:	10-20	CHa:	0-1	
	QZ and KF.					

NANIKA INTRUSIONS

9a.

M147,148,149,150	Medium to coarse-grained pinkish grey porphyritic HB-BT quartz monzonite.	QZp:	4-5	HBg:	1-2
	Anhedral quartz "eyes" characteristic.	PLp:	25-30	BTg:	2-3
	Euhedral PL, BT, and HB phenocrysts.	KFp:	2-3	MTg:	1-2
	Moderate to intense oxidation.	HBp:	2-3	PYg:	1-4
	Occasional euhedral KF phenocrysts.	BTp:	3-4	LMo:	1-5
	QZ rich groundmass with KF and PL.	QZg:	15-20	MSa:	1-3
	Abundant PY, minor chalcopyrite.	PLg:	10-15	CLa:	tr-2
		KFg:	25-30		

APPENDIX B

ANALYTICAL PROCEDURES

METHOD

Chemical analyses were determined using the Philips 4500 fully automated X-ray fluorescence spectrometer, at the University of Western Ontario. Samples to be analyzed were crushed to a fine powder, mixed with boracic acid and pressed into a circular disc. The disc was then loaded into a sample holder and automatically fed to the machine. Counts were determined for both the unknown and internal monitor samples. The data were printed on a teletype and punched on a paper tape which was then used to generate computer cards. A computer program applied the necessary correction factors to the raw data. The calculated composition of the sample analyzed was punched on cards and these were run through a second program which calculated the CIPW molecular norm. Loss on ignition was determined by baking a 2 gram aliquot of the sample in a ceramic crucible for 2 hours at 900°C.

DISCUSSION OF RESULTS

The results obtained are considered to be good approximations of the true chemical composition of the samples analyzed. The precision and accuracy of the method were checked by periodically analyzing samples of known composition. Comparison of the values obtained with acceptable analyses of the standards as given by the U.S.G.S., are presented in the following table.

STANDARD	AGV-1		GSP-1		G-1		PCC-1	
	USGS	XRF	USGS	XRF	USGS	XRF	USGS	XRF
SiO_2	58.99	60.20±0.11	67.27	68.85±0.12	69.19	69.90±0.07	41.87	42.62±0.17
TiO_2	1.08	1.11±0.01	0.69	0.65±0.01	0.53	0.44±0.01	0.02	0.00±0.00
Al_2O_3	17.01	16.53±0.10	15.11	14.12±0.08	15.34	14.56±0.03	0.85	1.27±0.02
*Fe_2O_3	6.08	6.70±0.03	4.33	3.81±0.02	2.76	2.47±0.01	4.88	9.34±0.07
MnO	0.09	0.10±0.00	0.04	0.04±0.00	0.03	0.03±0.00	0.12	0.14±0.00
MgO	1.49	1.49±0.06	0.95	1.20±0.01	0.78	1.17±0.02	43.56	43.41±0.19
CaO	4.98	5.09±0.04	2.03	2.07±0.01	1.98	2.02±0.02	0.53	0.59±0.01
Na_2O	4.33	4.28±0.02	2.88	2.81±0.04	4.15	4.02±0.03	0.05	0.00±0.00
K_2O	2.89	2.89±0.02	5.48	5.37±0.04	4.51	4.40±0.02	0.01	0.00±0.00
P_2O_5	0.48	0.47±0.01	0.28	0.31±0.01	0.14	0.16±0.01	0.01	0.00±0.00
No. of Analyses	5		8		4		3	

* Total Fe as Fe_2O_3

In general, there is close agreement between the analytical (XRF) and U.S.G.S. acceptable values for TiO_2, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5. Values determined for SiO_2 are slightly greater, and Al_2O_3 and total Fe as Fe_2O_3 are slightly less than the U.S.G.S. values. The small standard deviations calculated from multiple analyses of the standard samples indicate a high degree of precision for the analytical method used.

The major oxide compositions of the samples analyzed are presented in Tables 8 - 12. When loss on ignition was added to the sum of the calculated weight percents of the oxide components, most of the totals were between 99 to 101 percent. However, several of these totals exceed 101%, and these samples invariably had relatively large loss on ignition values. This is because the computer program used to calculate the major oxide composition from the raw analytical data, does not make adjustments for volatile content of the sample.

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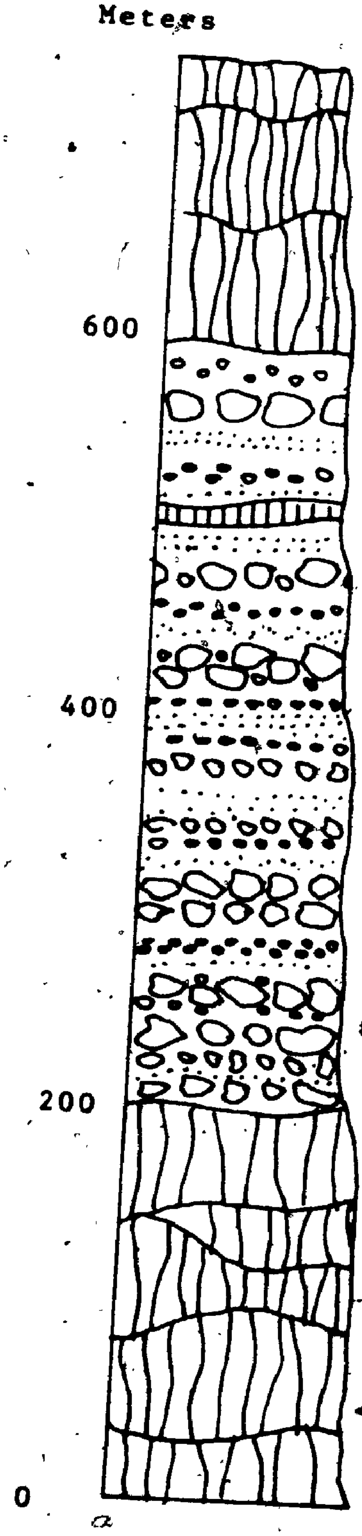
	ASARCO Exploration Co. of Can., Ltd. 1973-present

B. Swing Peak Formation - South slope of Swing Peak ridge.



MEMBFR C - Massive dark grey, fine-grained augite-hornblende latite-andesite. Relatively fresh with prominent columnar jointing

Purplish grey porphyritic latite-andesite

MEMBER B - Massive stratified lahar. Mixed very coarse and fine-grained beds. Clasts in lahar mainly latite-andesite. Minor crystal tuff, tuff-breccia, and sandstone interbedded with lahar.

MEMBER A - Massive greenish grey to light grey fine to medium grained porphyritic augite-hornblende latite-andesite. Minor dacite toward base of section.

APPENDIX D

K- Ar ANALYTICAL DATA

Specimen No	Location	Rock Type	Mineral	% K ± S	Ar^{40} Rad gm x 10^{5}	Apparent Age (m.y.)	Source
D-80	Swing Peak	Kasalka Int. latite - andesite.	Whole Rock	1.27 ± 0.01	0.544	104 ± 8	Teledyne Isotopes
M-211	Swing Peak	Mt. Baptiste Fm. dacite tuff.	Whole Rock	1.79 ± 0.01	0.776	105 ± 5	Teledyne Isotopes
D-131	Swing Peak	Swing Peak Fm. latite-andesite	Whole Rock	1.05 ± 0.00	0.376	87 ± 4	Teledyne Isotopes
NC-67-44	Huckleberry Mountain	Bulkley Int. Porphyritic granodiorite	Biotite	4.25 ± 0.01	1.435	83.4 ± 3.2	UBC/BCDM (Carter, 1974)
NC-9	Coles Creek	Bulkley Int. Porphyritic granodiorite	Biotite	6.89 ± 0.04	2.337	83.8 ± 2.8	UBC/BCDM (Carter, 1974)
-	Troitsa Stock	Bulkley Int. Granodiorite	Biotite	7.09 ± 0.03	2.069	75.7 ± 2.3	UBC (Cawthorn, 1973
-	Bergette	Bulkley Int. Porphyritic qz. monzonite.	Biotite	N.A.	N.A.	76.7 ± 2.5	UBC (Carter)
NC-67-8	Berg	Coast Int. qz diorite	Biotite	2.64 ± 0.01	0.495	46.8 ± 1.5	UBC/BCDM (Carter, 1974)
NC-67-13	Berg	Coast Int. qz diorite	Biotite	6.97 ± 0.05	1.396	49.9 ± 2.1	UBC/BCDM (Carter, 1974)
NC-67-11	Berg	Nanika Int. Porph qz monzonite	Biotite	6.76 ± 0.05	1.413	52.0 ± 2	UBC/BCDM (Carter, 1974)
NC-67-10	Berg	Nanika Int. Porph qz latite	Biotite	6.56 ± 0.06	1.249	47.0 ± 3	UBC/BCDM (Carter, 1974)

Abbreviations: S = Standard deviation; N.A. = data unavailable
UBC = University of British Columbia, geochronology laboratory
BCDM = B. C. Department of Mines Sample.

N.B. Analytical procedures used by U.B.C. geochronology laboratory are summarized in Carter, 1974; Constants used for age calculation are $\lambda_{\beta} = 4.72 \times 10^{-10}\ yr^{-1}$, $\lambda_{e} = 0.585 \times 10^{-10}\ yr^{-1}$ and $K^{40} = 1.19 \times 10^{-4}$ atom % of natural K.

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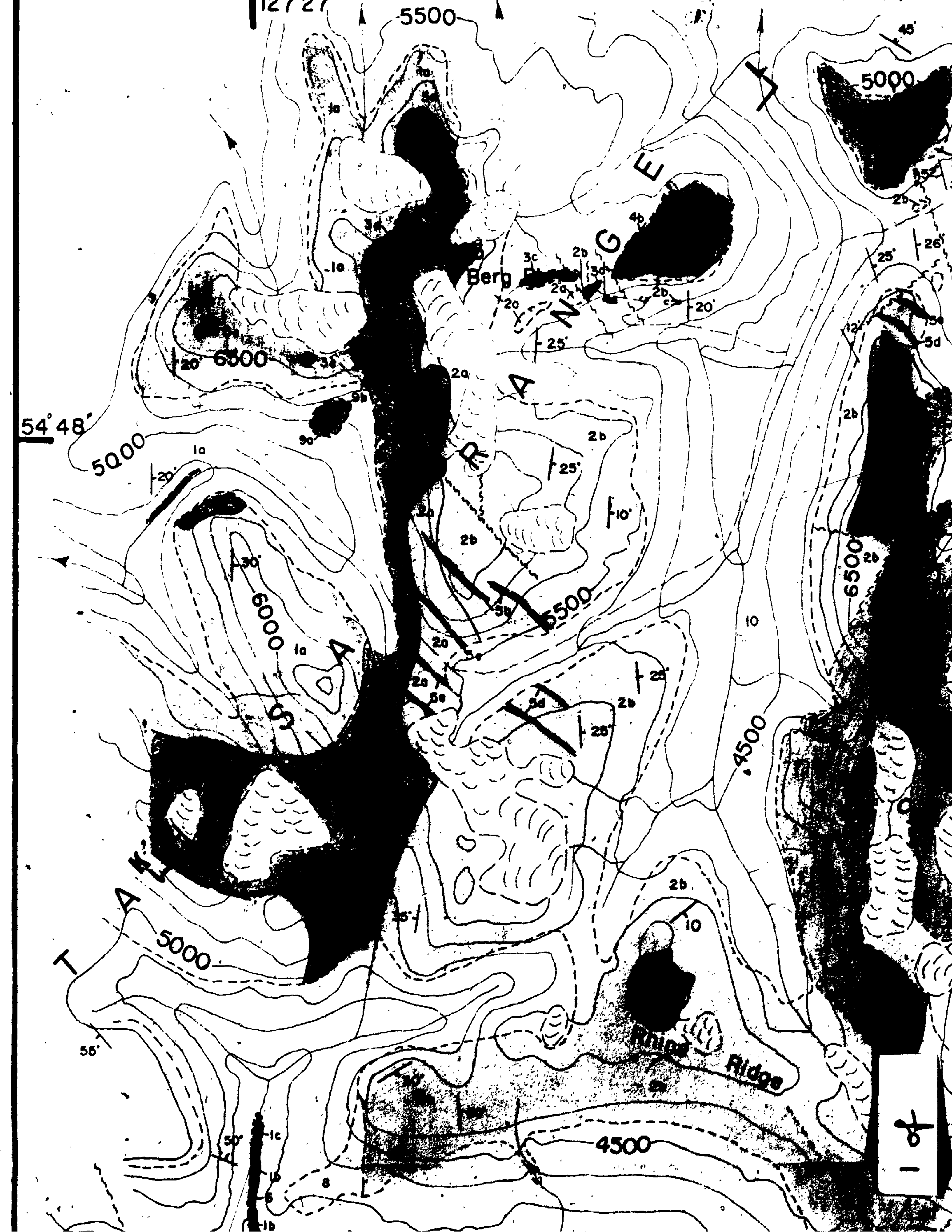
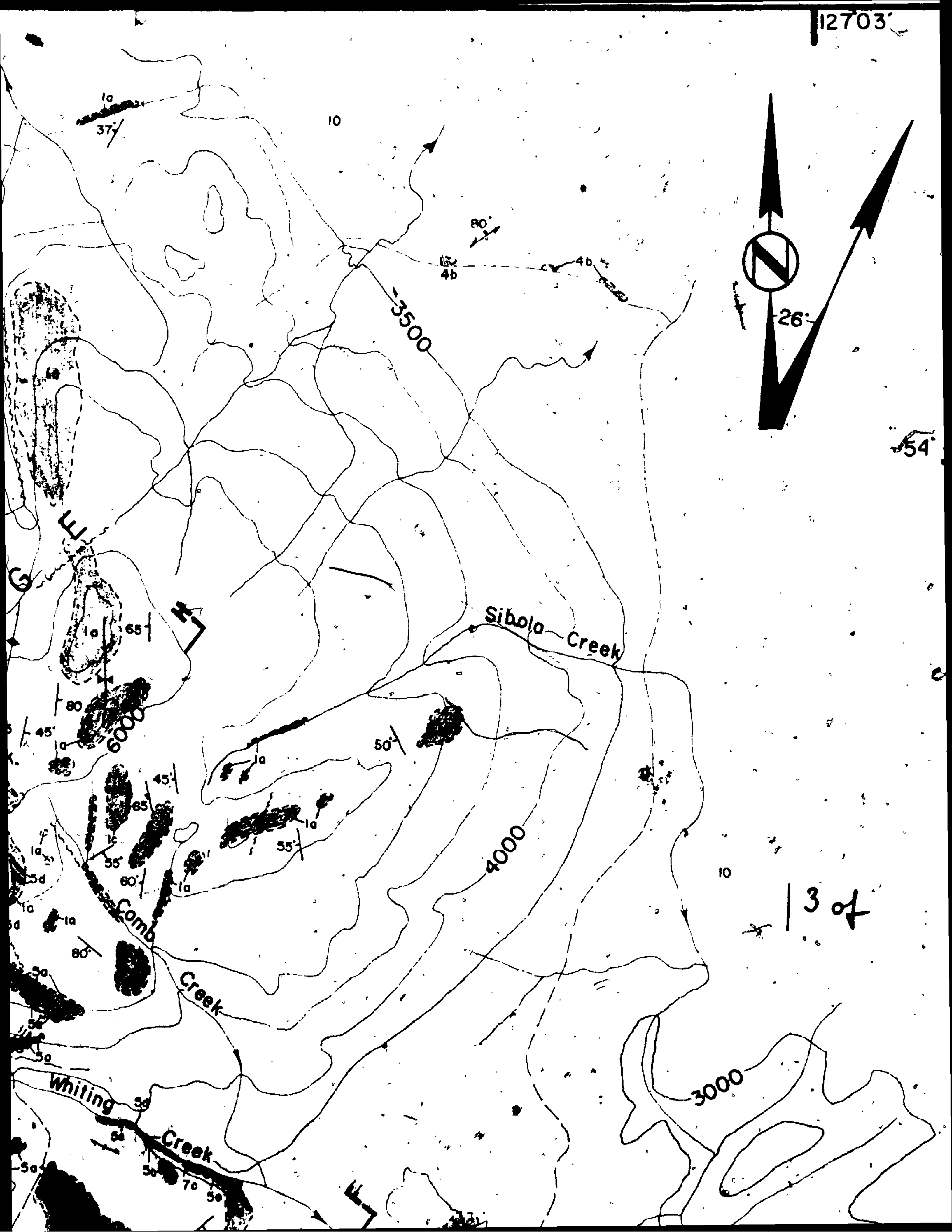
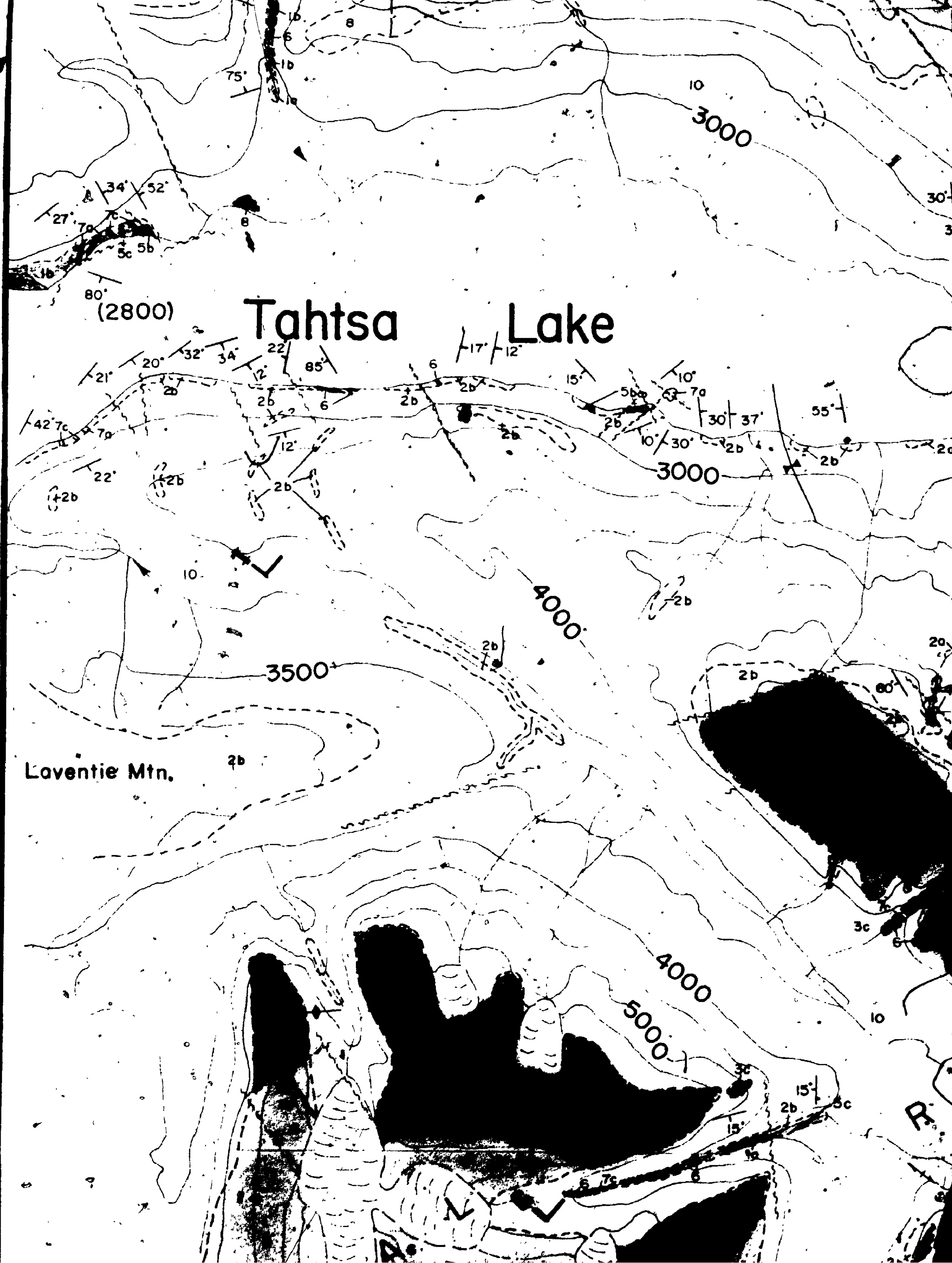


5500
5000
R A N G E
Berg
6500
54°48′
5000
6000
6500
4500
5000
Rhine Ridge
4500

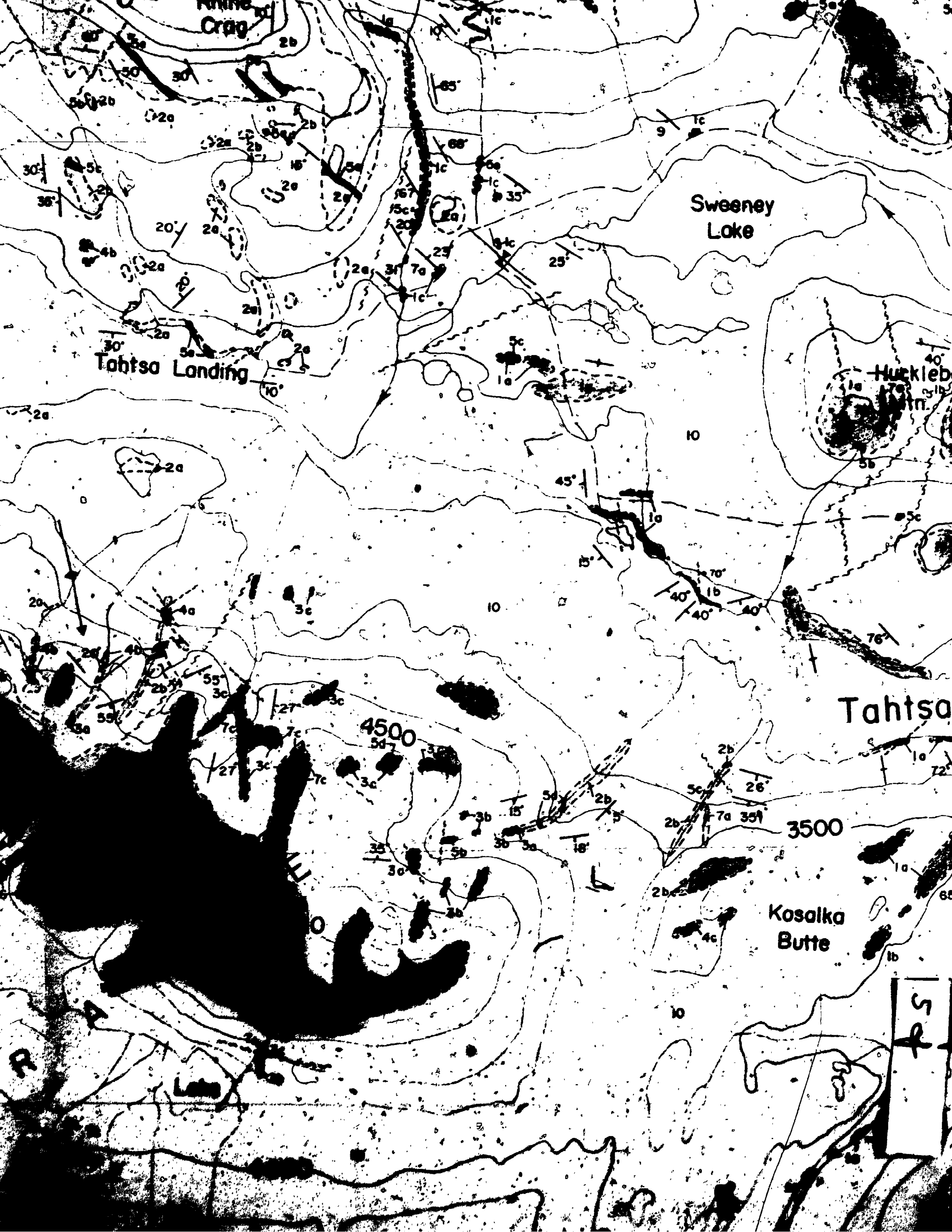
Berg Road
4000
5000
Mt Sweeney
7216
5500
6500
Rhine Creek
Rhine Crag
Ola Pk.



12703'
1a
37°
10
80°
4b
4b
3500
N
26°
54°
Sibola Creek
1a
65
80
45°
6000
1a
50°
1a
45°
65
1c
1a
55°
55°
60°
1a
4000
10
3 of
1a
5d
1a
80°
Comb
Creek
5a
3000
Whiting
Creek
5a
7c



Tahtsa Lake
Laventie Mtn.
(2800)
3000
3000
3500
4000
4000
5000
10
10
10
8
8
6
2b
5b
5c
7a
7c
1b
3c
R



Crag
Sweeney
Lake
Tahtsa Landing
Tahtsa
4500
3500
Kosalka
Butte
Lake

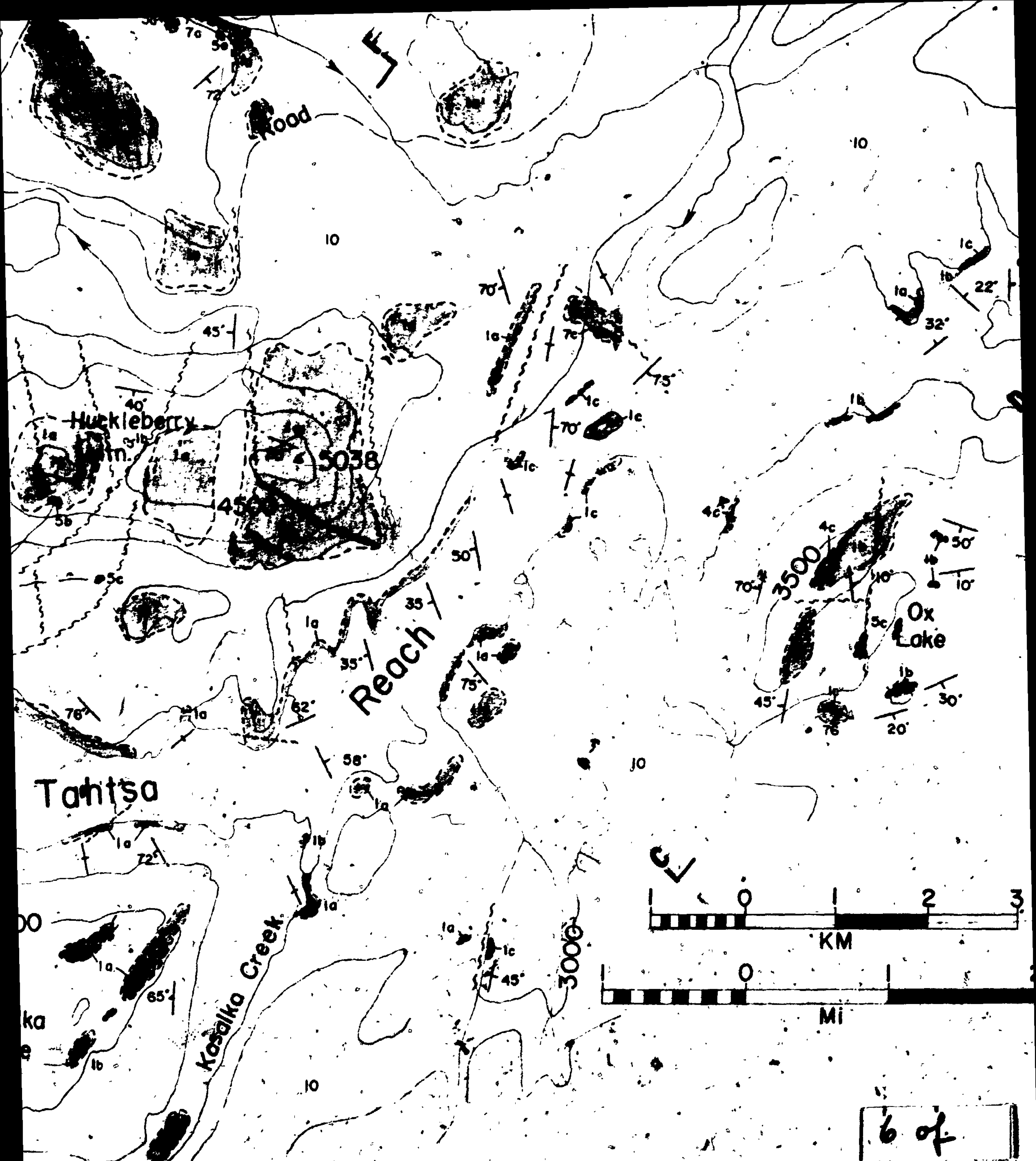
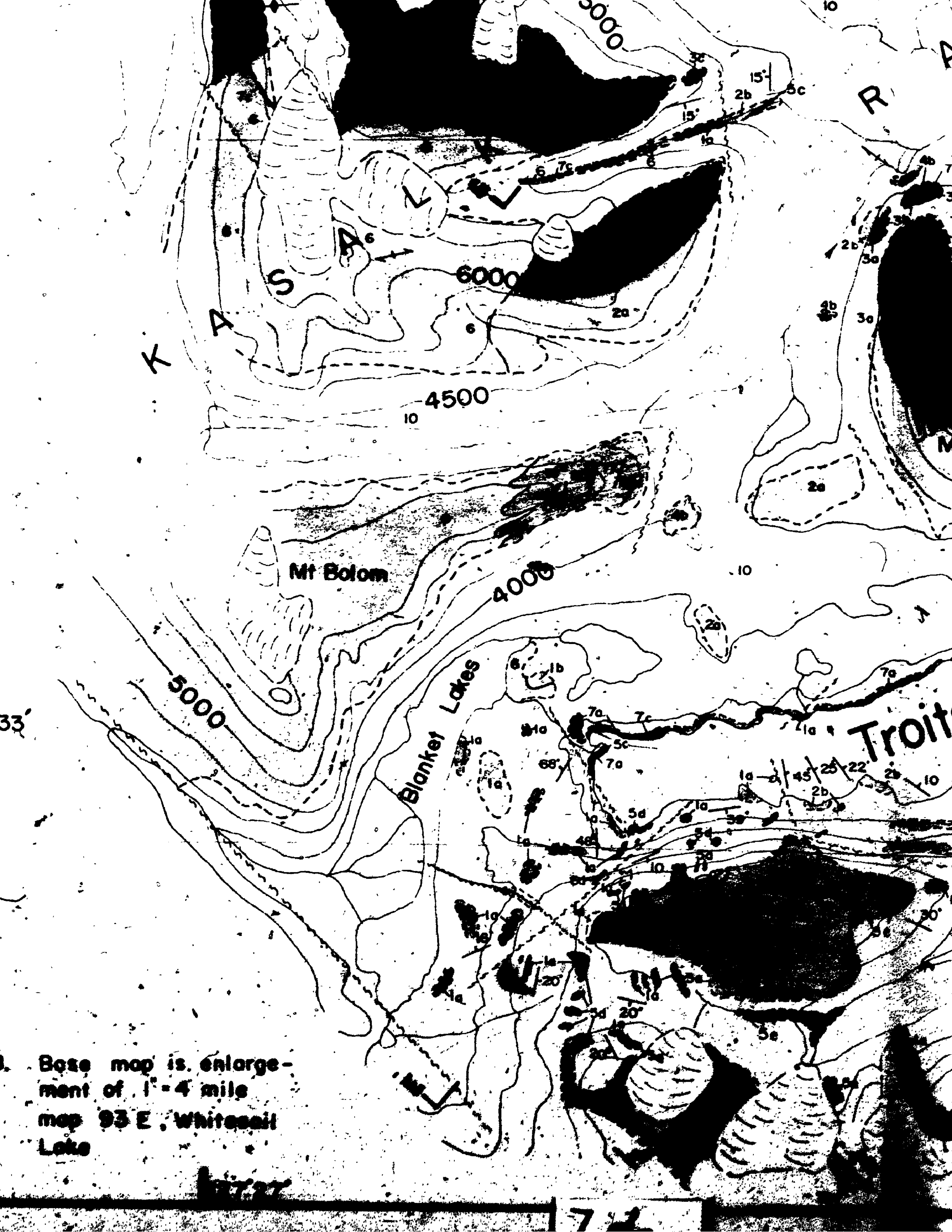


FIGURE 23
GEOLOGY OF TAHTSA LAKE AREA

LEGEND



3. Base map is enlargement of 1" = 4 mile map 93 E, Whitesail Lake

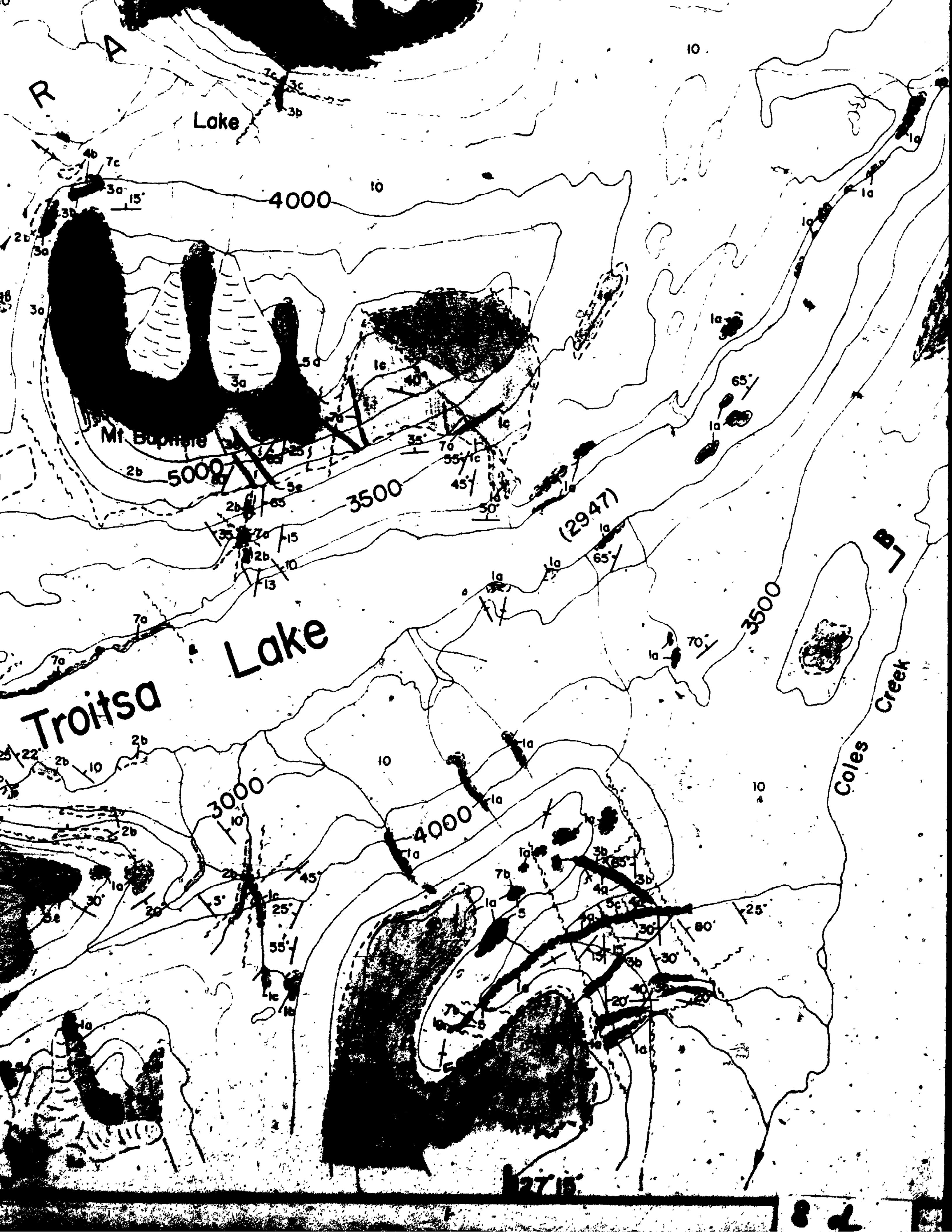

R A
Lake
4000
Mt Baptiste
5000
3500
(2947)
Troitsa Lake
3000
4000
3500
Coles Creek
B
127°15'

FIGURE 23
GEOLOGY OF TAHTSA LAKE AREA

LEGEND

Pleistocene to Recent

[10] Till, alluvium

Eocene

Nanika Intrusions: a. porphyritic quartz monzonite b. porphyritic quartz latite

Coast Intrusions: quartz diorite

Upper Cretaceous

Dykes: a. rhyodacite; b. andesite; c. basalt, lamprophyre

[6] Mt Bolom Intrusions: porphyritic granophyre

Bulkley Intrusions: a. granodiorite; b. quartz diorite; c. porphyritic granodiorite; d. quartz porphyry rhyolite; e. porphyritic quartz monzonite

[4] Kasalka Intrusions: a. porphyritic dacite; b. latite-andesite; c. diorite

Kasalka Group: a. basal conglomerate; b. Mt. Baptiste Fm. - welded tuff, rhyodacite, breccia; c. Swing Peak Fm. - latite-andesite, lahar; d. Bergette Fm. - rhyodacite, tuff

Lower Cretaceous (Albian)

[2] Skeena Group: a. basalt; b. sandstone, shale

Jurassic

Hazelton Group: a. lapilli, lithic, and crystal tuff, tuff-breccia, andesite; b. welded tuffs, rhyodacite, dacite; c. chert, argillite, volcanic wacke, conglomerate, minor tuff

Bedding - inclined, vertical
Foliation - inclined, vertical
Major fault
Geologic contact - defined, assumed
1000 Topographic contour (500 foot interval)
Snowfield

Anticline
Syncline
Outcrop

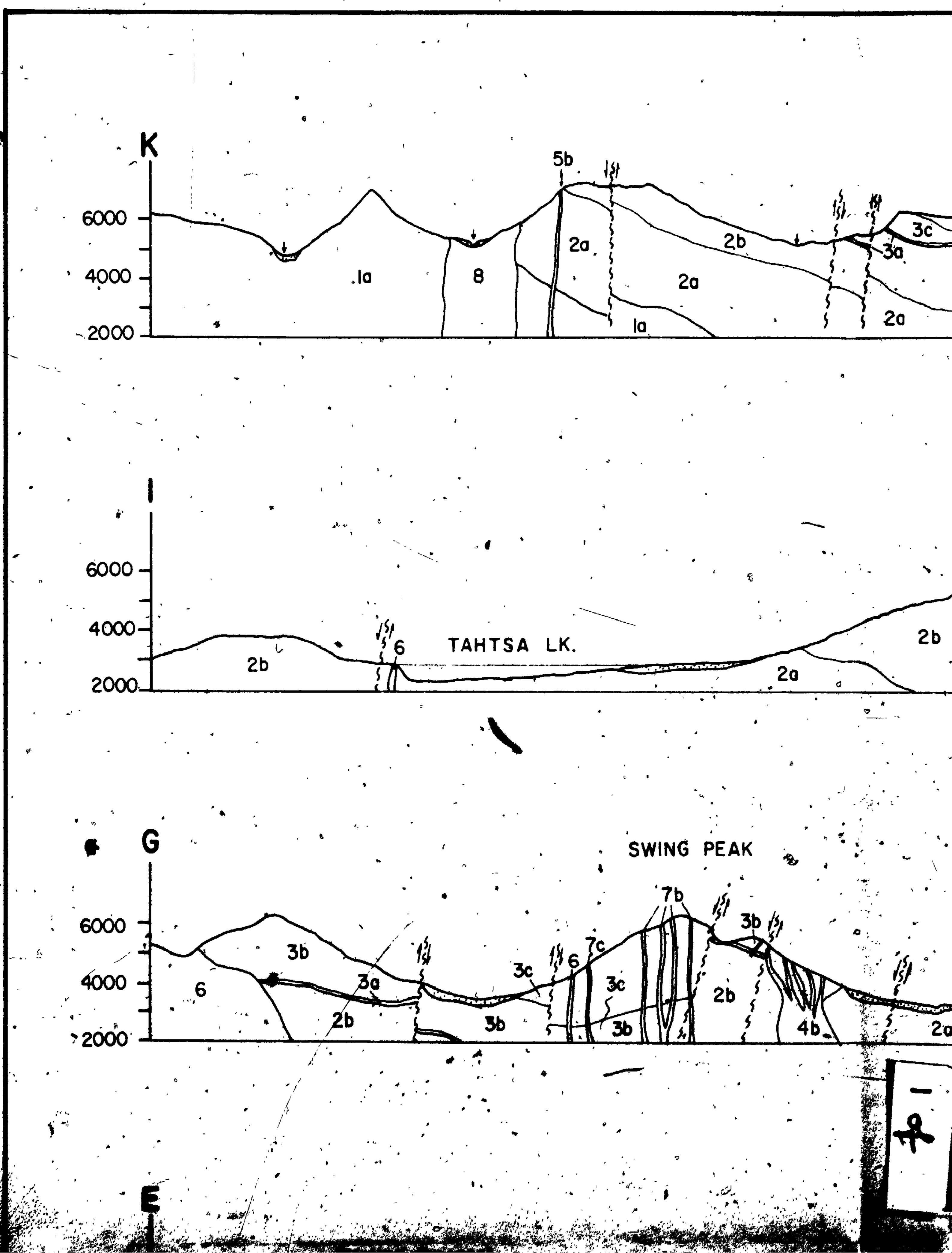
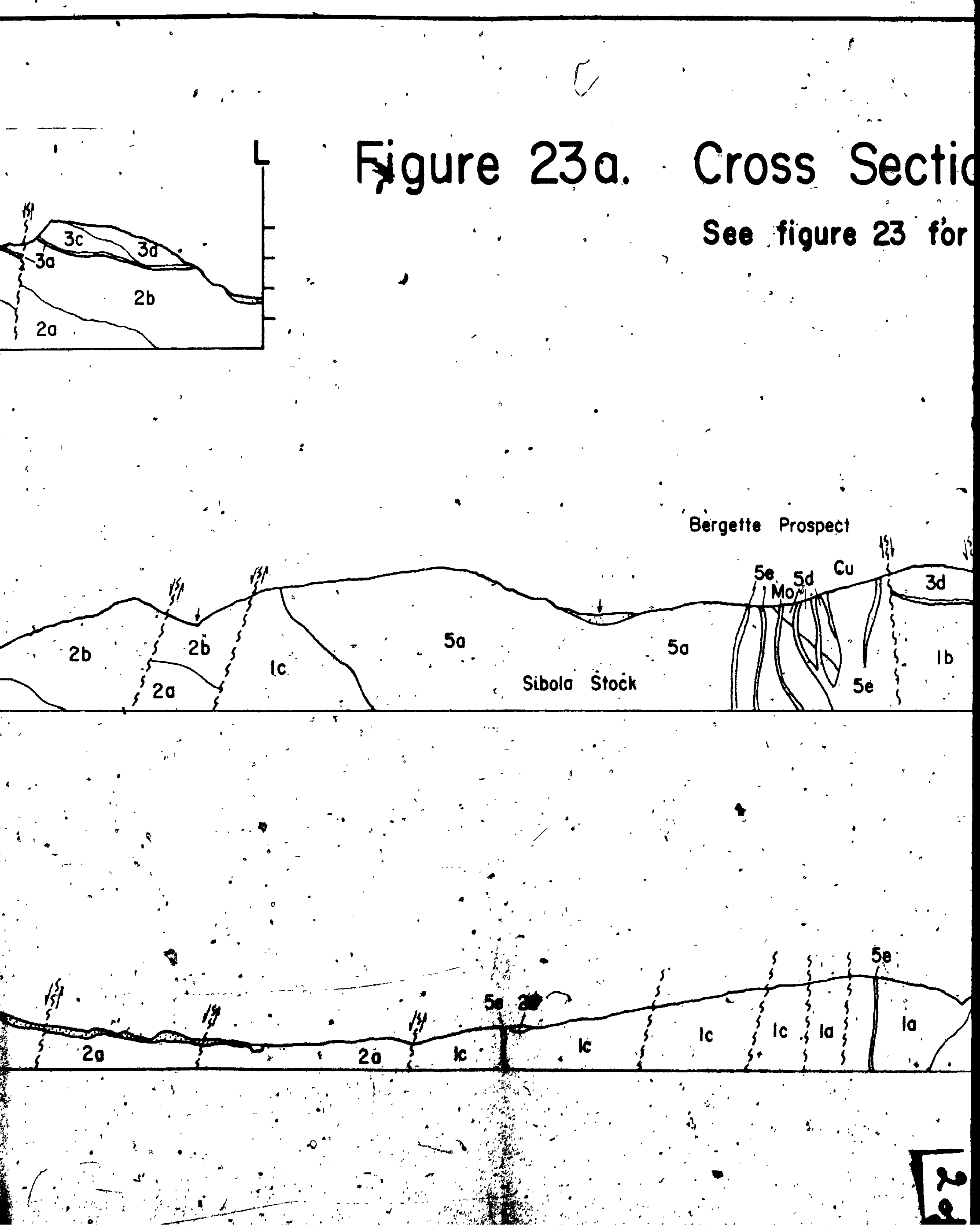

K
6000
4000
2000
5b
2a
2b
3c
3a
1a
8
2a
1a
2a
I
6000
4000
2000
TAHTSA LK.
6
2b
2a
2b
G
SWING PEAK
6000
4000
2000
7b
3b
7c
6
3c
3b
3a
6
2b
3b
3c
3b
2b
4b
E

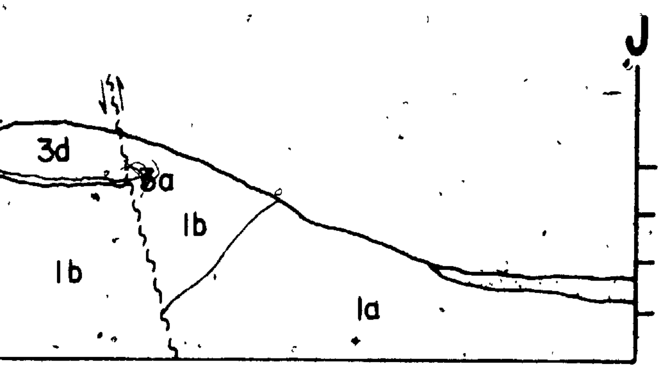
Figure 23a. Cross Sectio

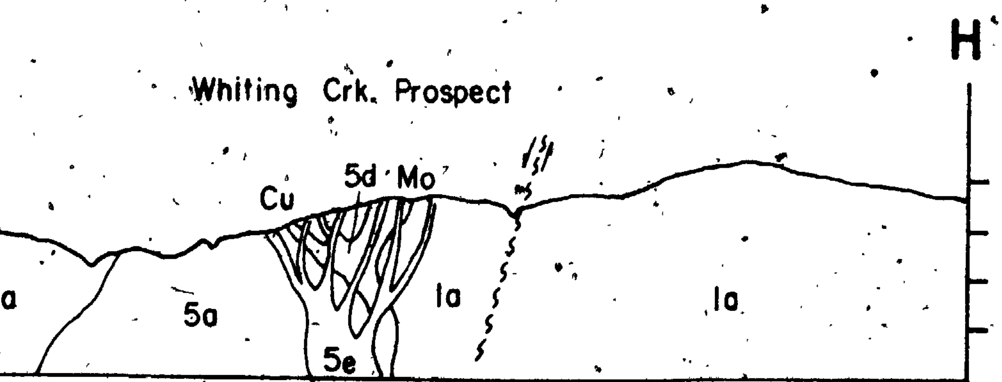
See figure 23 for

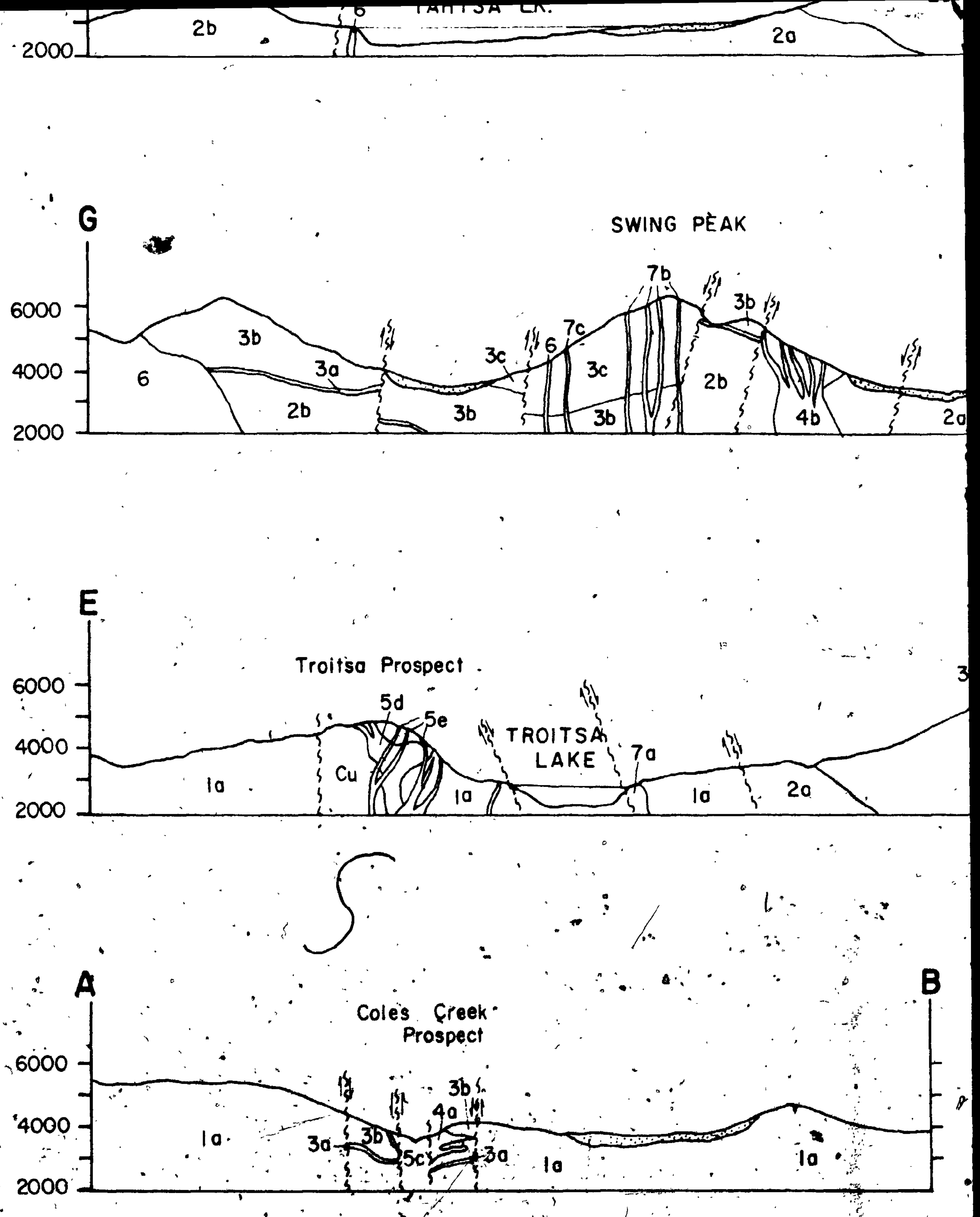


ctions, Tahtsa Lake Area

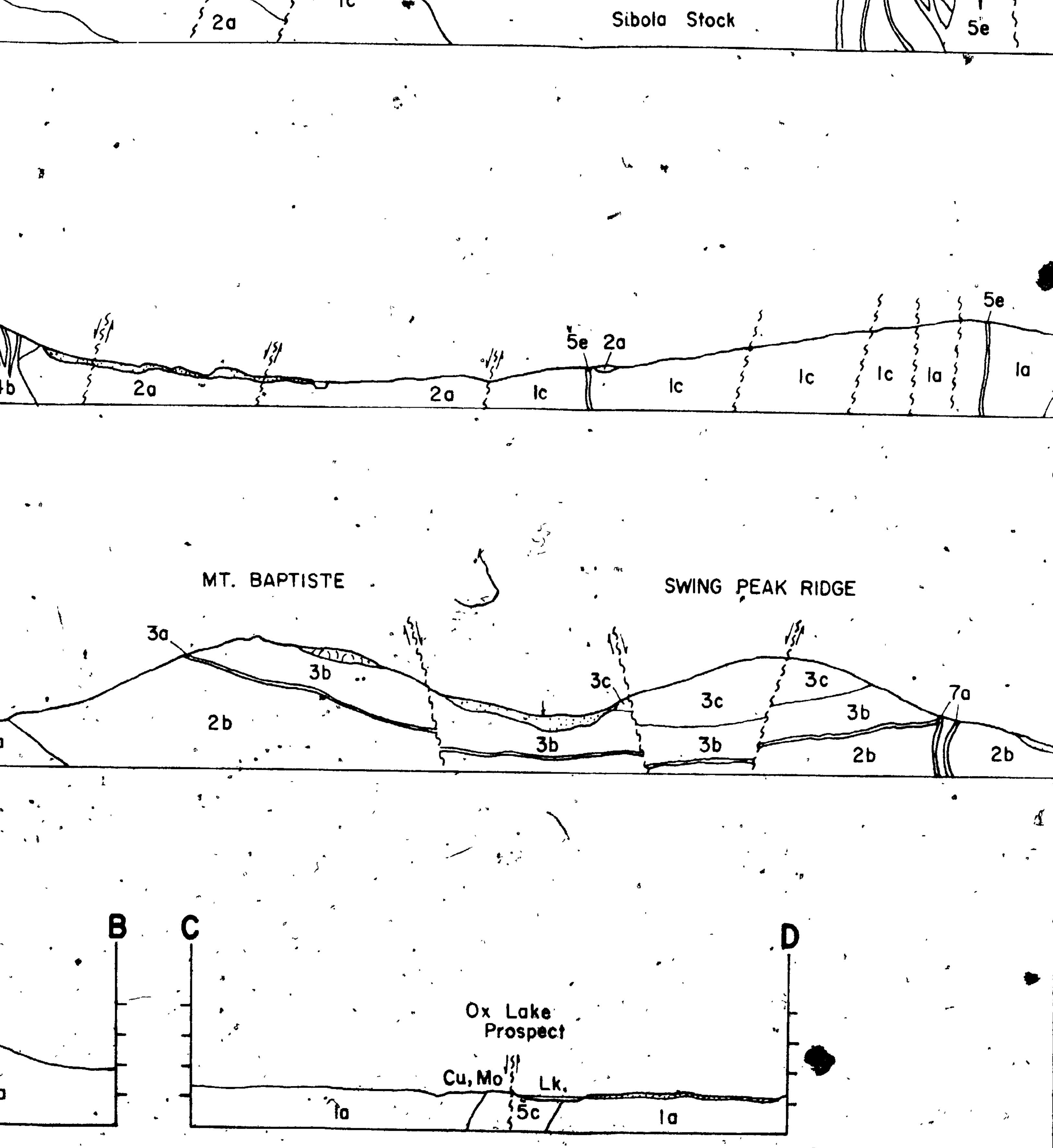
for legend and location of sections



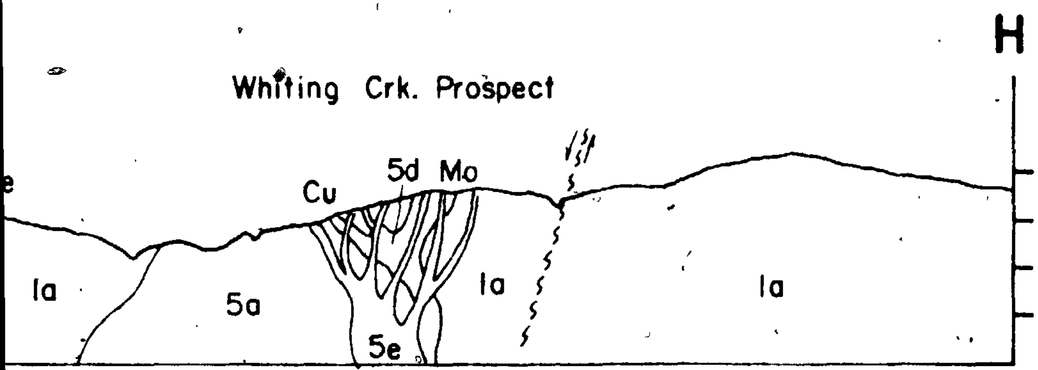


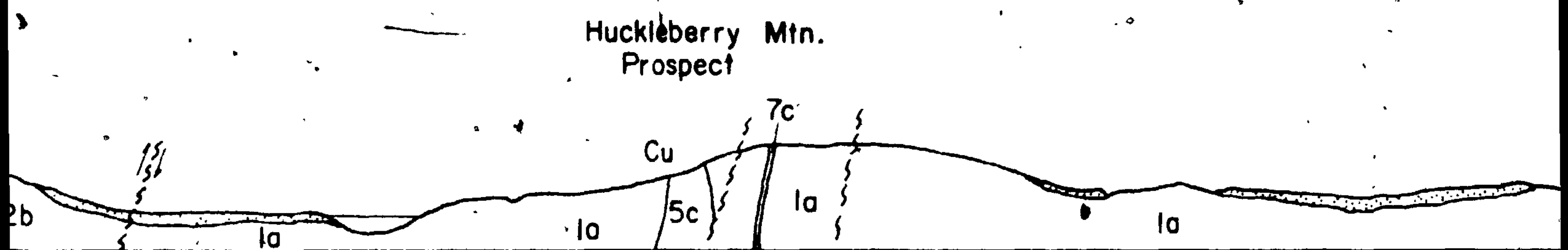


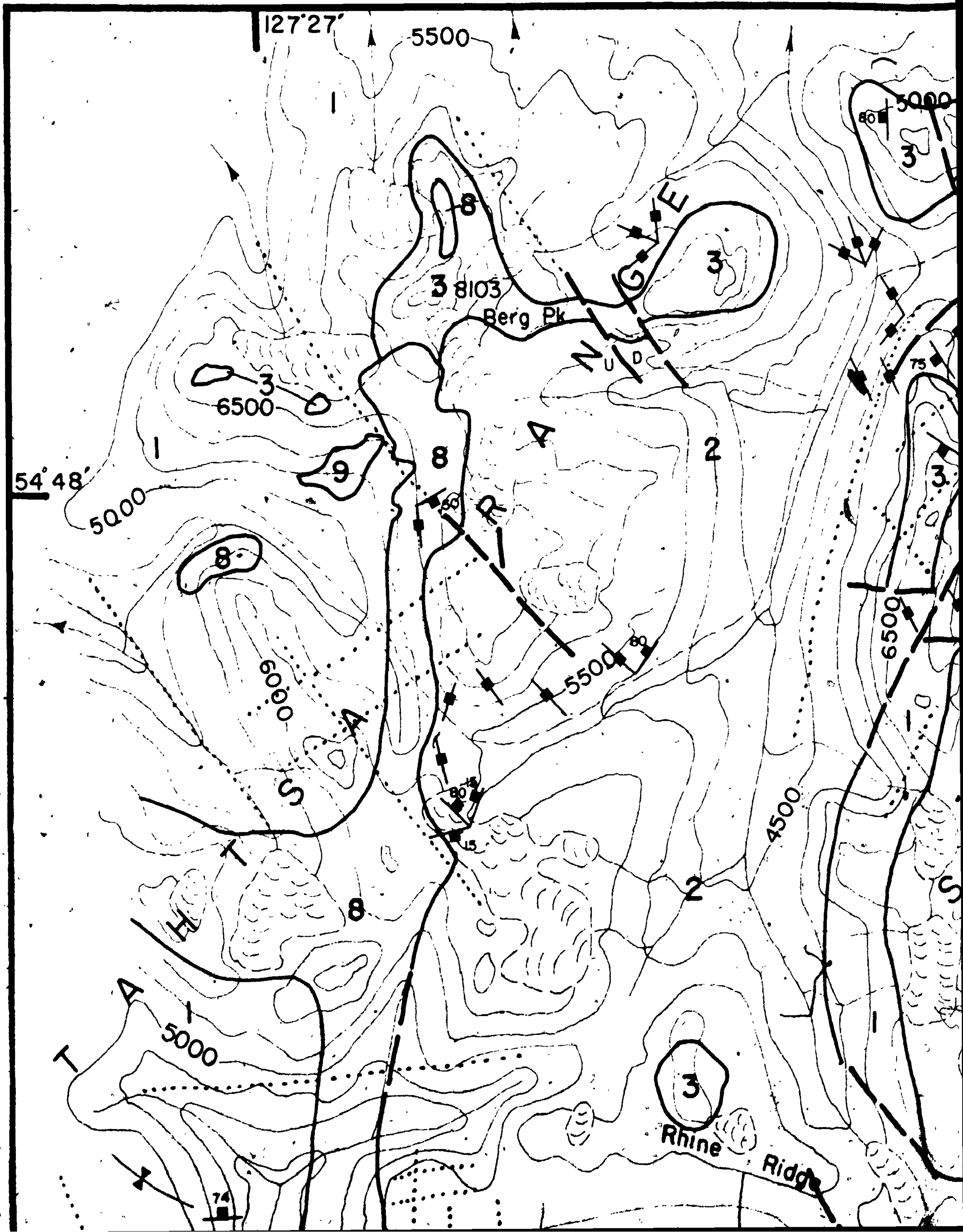
TAHTSA LK.
2000
2b
2a
6
G
SWING PEAK
6000
4000
2000
3b
6
3a
2b
3c
7c
7b
3c
3b
2b
4b
2a
E
Troitsa Prospect
6000
4000
2000
5d
5e
TROITSA LAKE
7a
1a
Cu
2a
A
B
Coles Creek Prospect
6000
4000
2000
3b
4a
3a
5c
1a

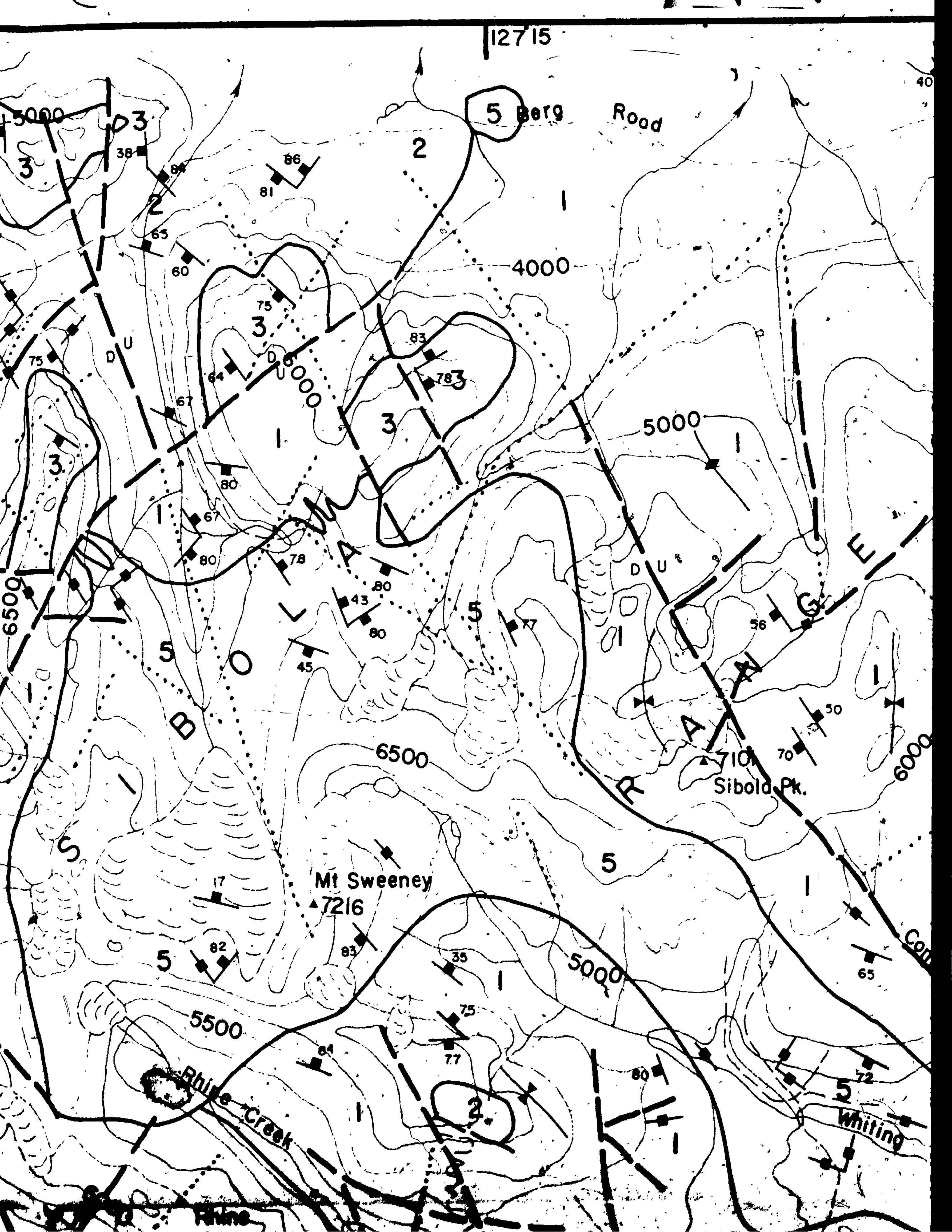

Sibola Stock
2a
Ic
5e
2a
Ic
Ia
MT. BAPTISTE
SWING PEAK RIDGE
3a
3b
3c
7a
2b
B
C
D
Ox Lake
Prospect
Cu, Mo
Lk.
5c
Ia

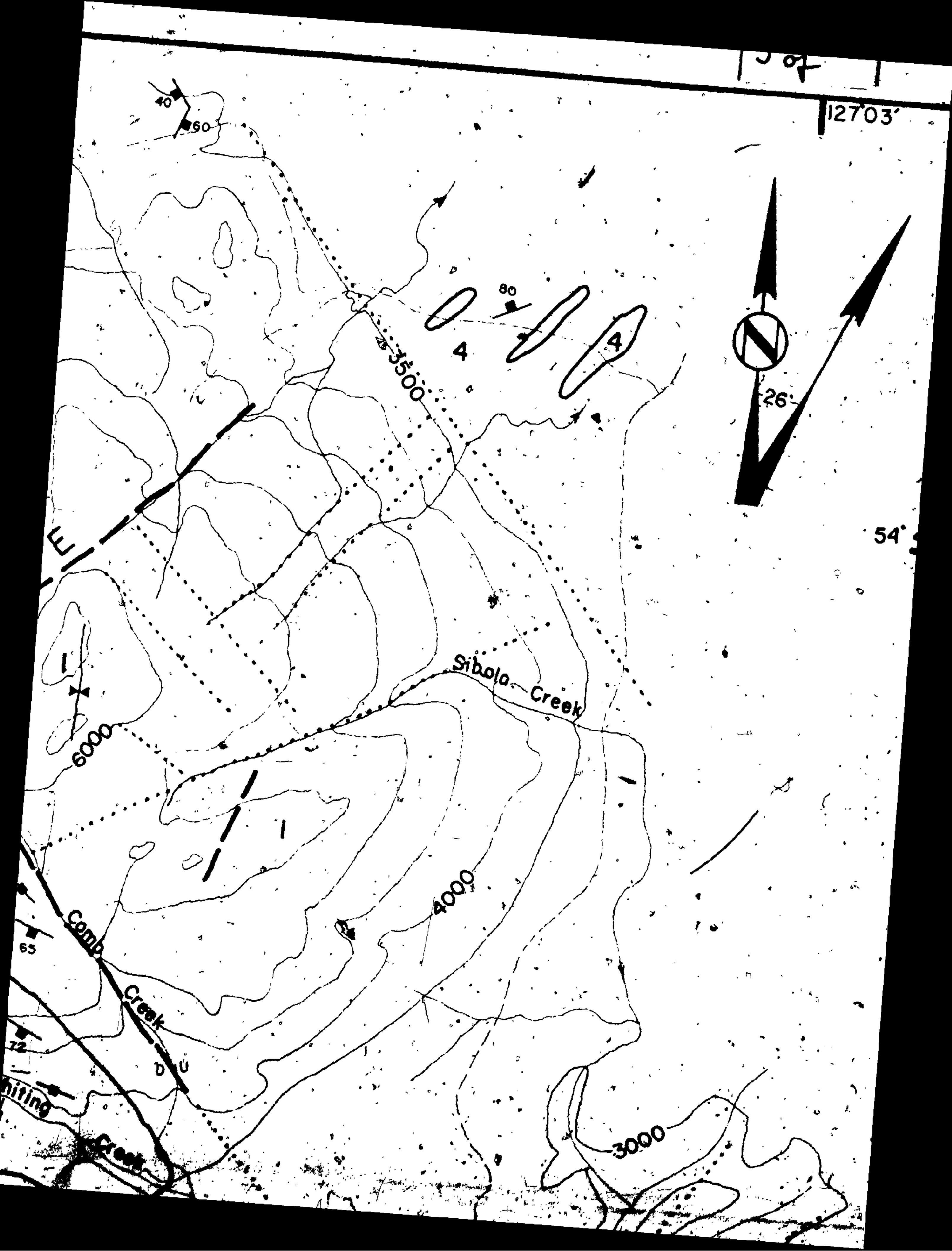

Ia

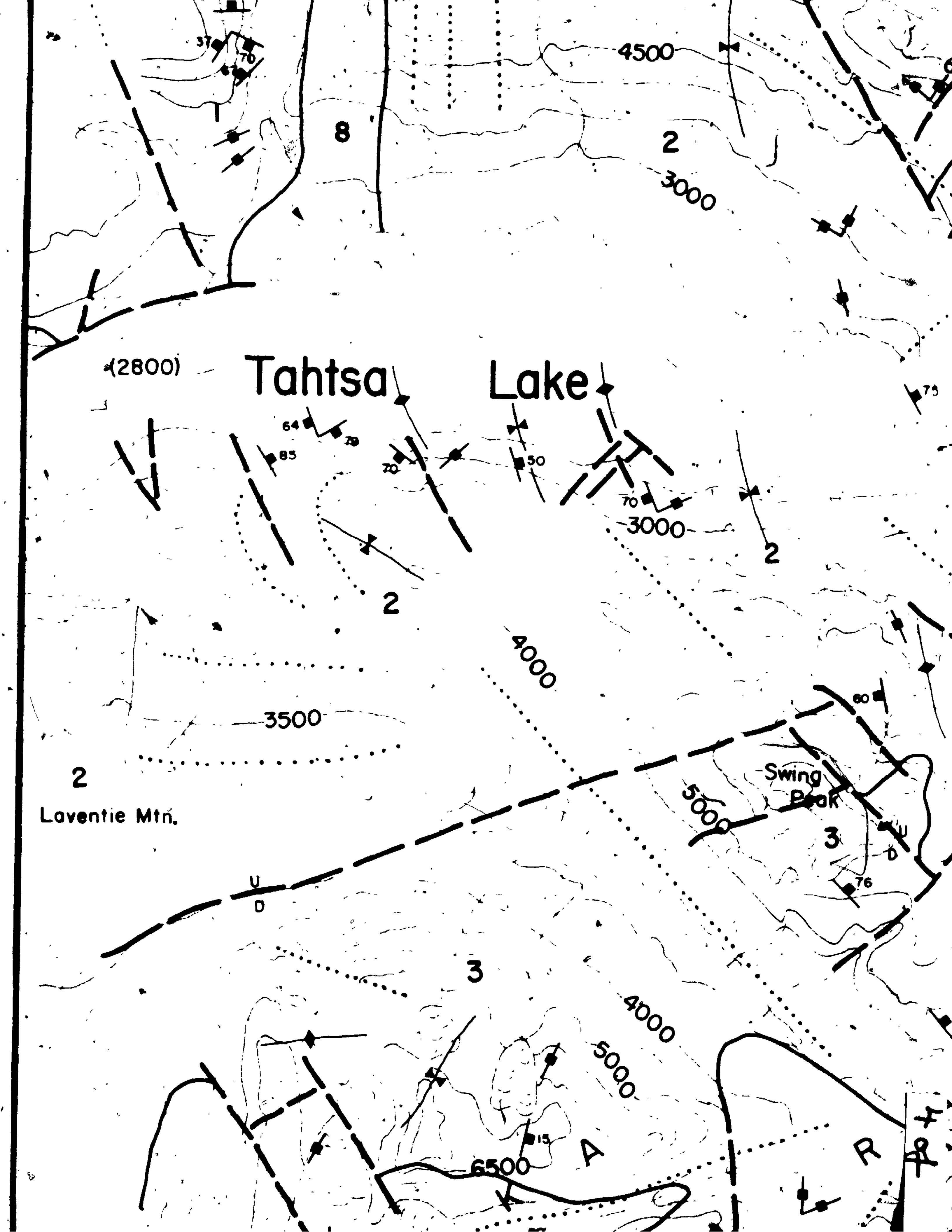

Whiting Crk. Prospect
H
Cu
5d
Mo
Ia
5a
5e
Ia
Ia


Huckleberry Mtn.
Prospect
7c
Cu
5c
Ia
2b
Ia
Ia
Ia

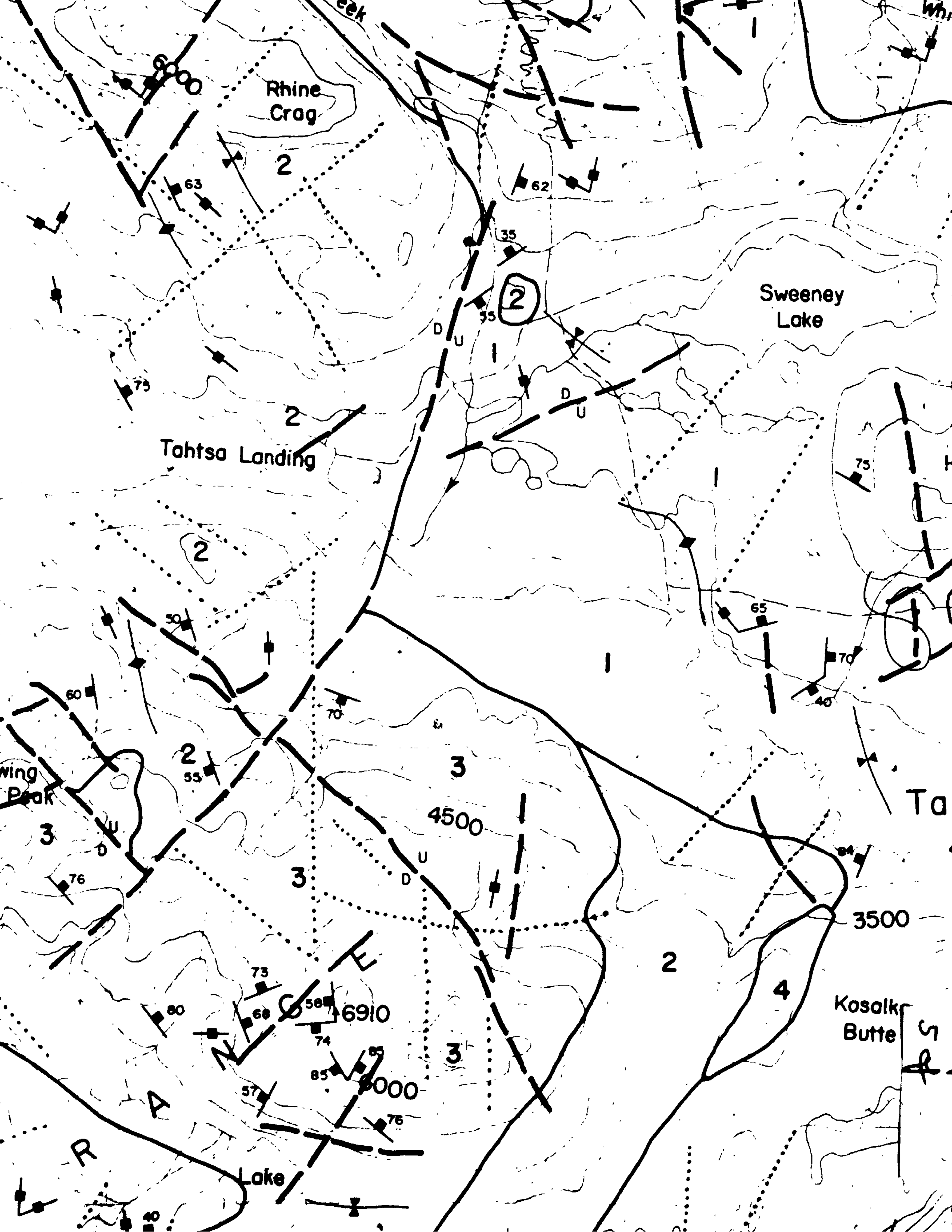

127°27′
54°48′
5500
5000
6500
6000
4500
8103
Berg Pk
Rhine Ridge
TAHTSA RANGE


127 15
5 Berg Rood
5000
4000
5000
6000
6500
RANGE
7101
Sibold Pk.
Mt Sweeney
7216
5500
5000
Rhine Creek
Whiting
Rhine


12°03'
54'
26'
N
40
60
80
4
4
3500
E
1
1
6000
Sibola Creek
4000
Comb
Creek
65
72
D
U
Creek
3000



Tahtsa Lake
Swing Peak
Laventie Mtn.
(2800)
4500
3000
3000
3500
4000
4000
5000
5000
6500
8
2
2
2
2
3
3
U
D
U
D
A
R
37
70
67
64
79
85
70
50
70
75
60
76
15



6000
Rhine Crag
2
63
62
35
2
55
D
U
1
Sweeney Lake
75
2
Tahtsa Landing
D
U
75
2
50
65
1
70
40
60
70
2
3
Peak
55
3
4500
U
D
76
3
84
3500
2
4
Kosalk Butte
E
73
58
6910
80
68
74
N
3
85
85
6000
57
76
A
R
Lake
40

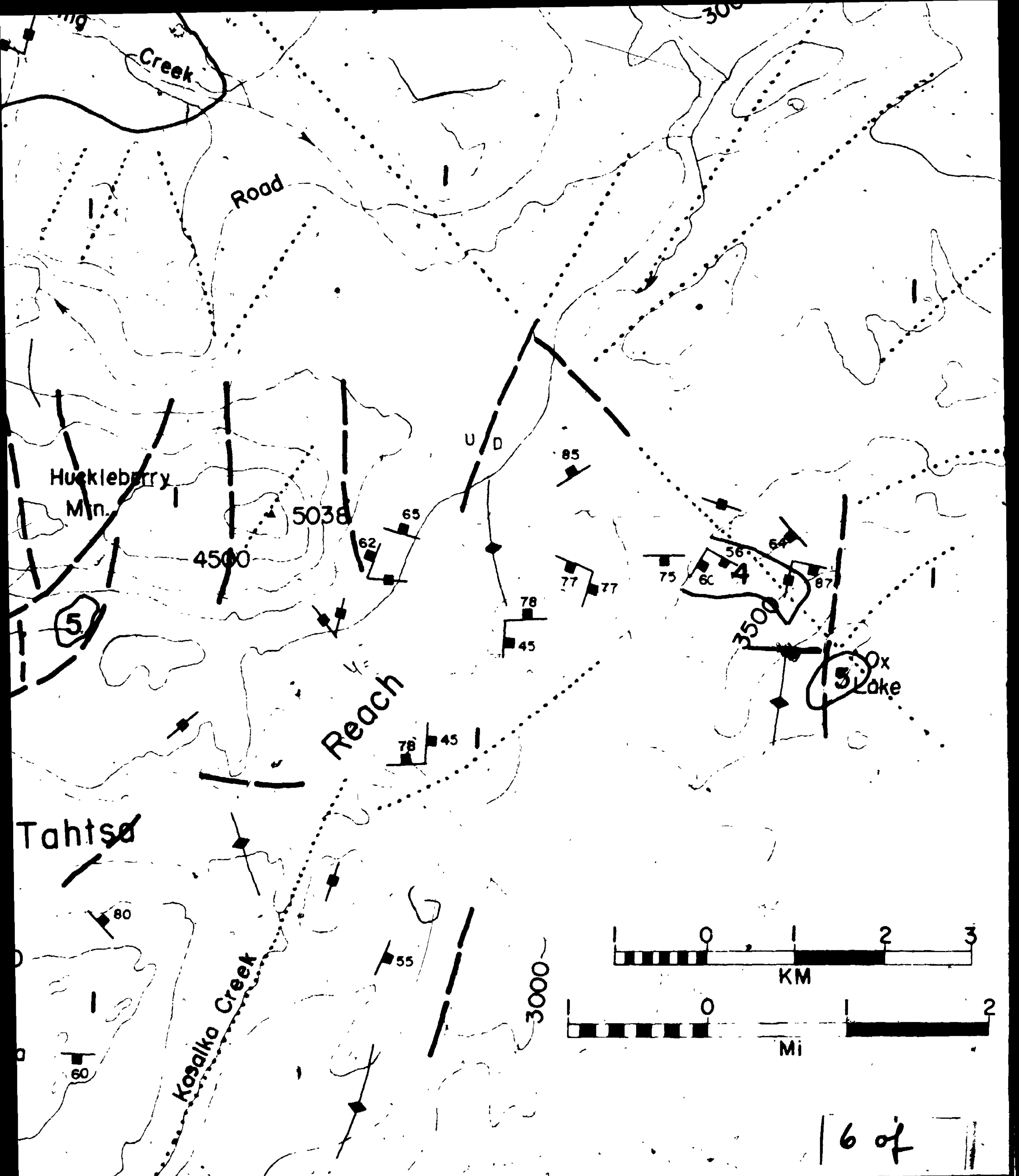


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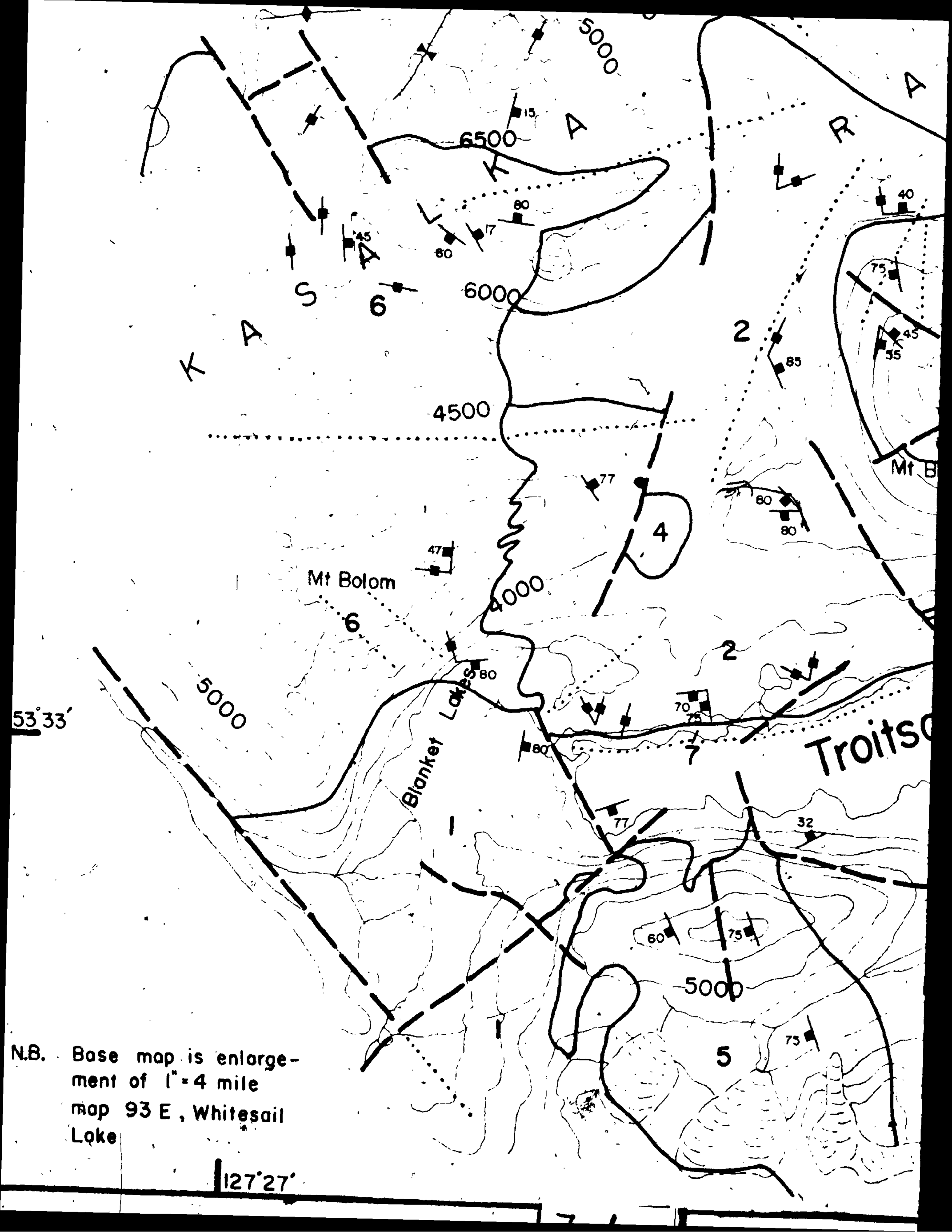
FIGURE 24
TECTONIC MAP of TAHTSA



KASKA
RA
Mt Bolom
Blanket Lakes
Troitsa
Mt B
6500
6000
5000
4500
4000
5000
5000
53°33′
127°27′
N.B. Base map is enlargement of 1" = 4 mile map 93 E, Whitesail Lake

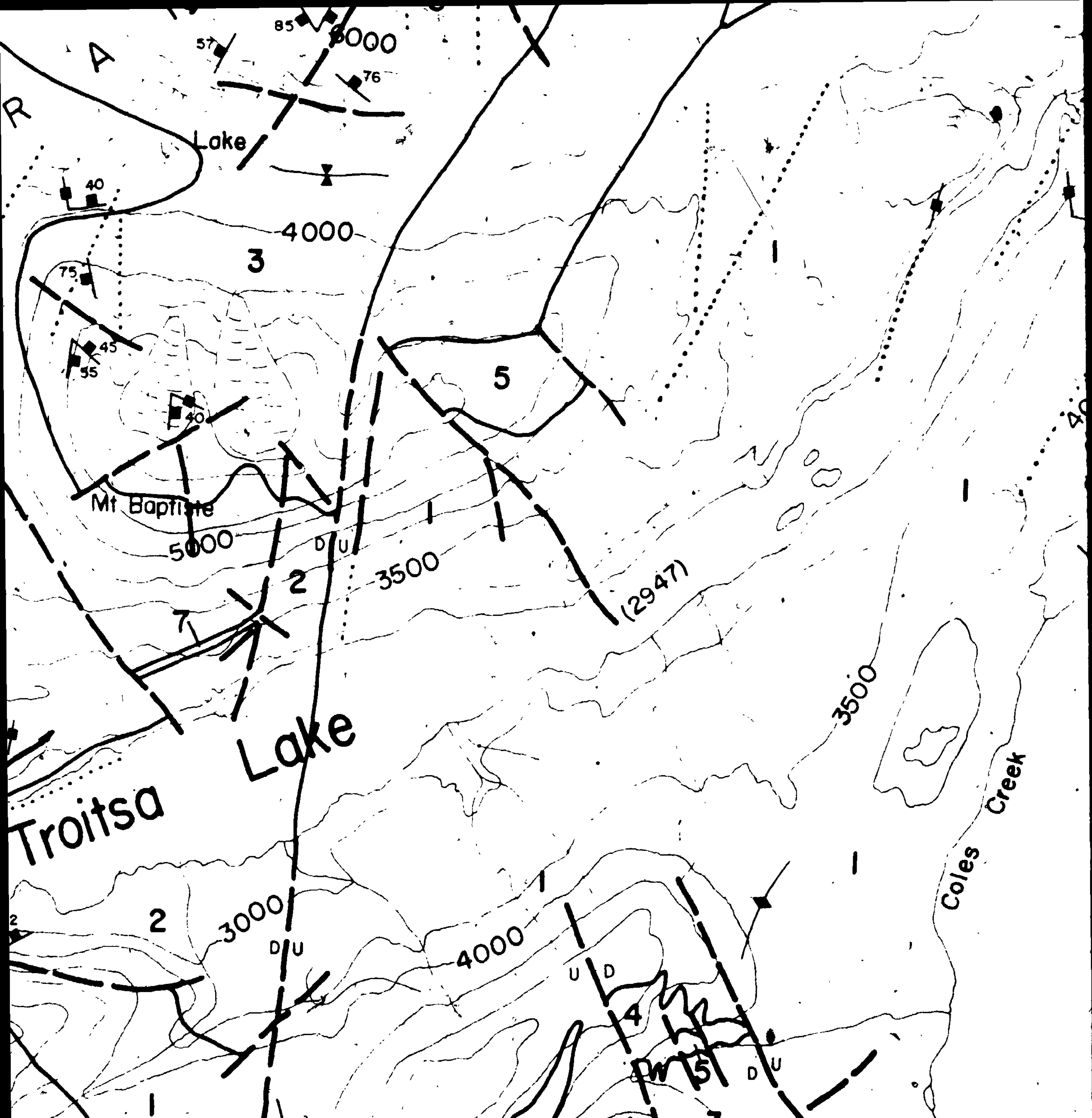

Lake
4000
3
5
Mt Baptiste
5000
3500
D U
2
7
(2947)
Troitsa
Lake
3500
Coles Creek
2
3000
D U
4000
U D
4
5
D U
3
5
5000
127°15'
8 of

FIGURE 24
TECTONIC MAP of TAHTSA LAKE AREA

LEGEND

9 NANIKA INTRUSIONS

8 COAST INTRUSIONS

7 DYKES

6 MT. BOLOM INTRUSIONS

5 BULKLEY INTRUSIONS

4 KASALKA INTRUSIONS

3 KASALKA GROUP

2 SKEENA GROUP

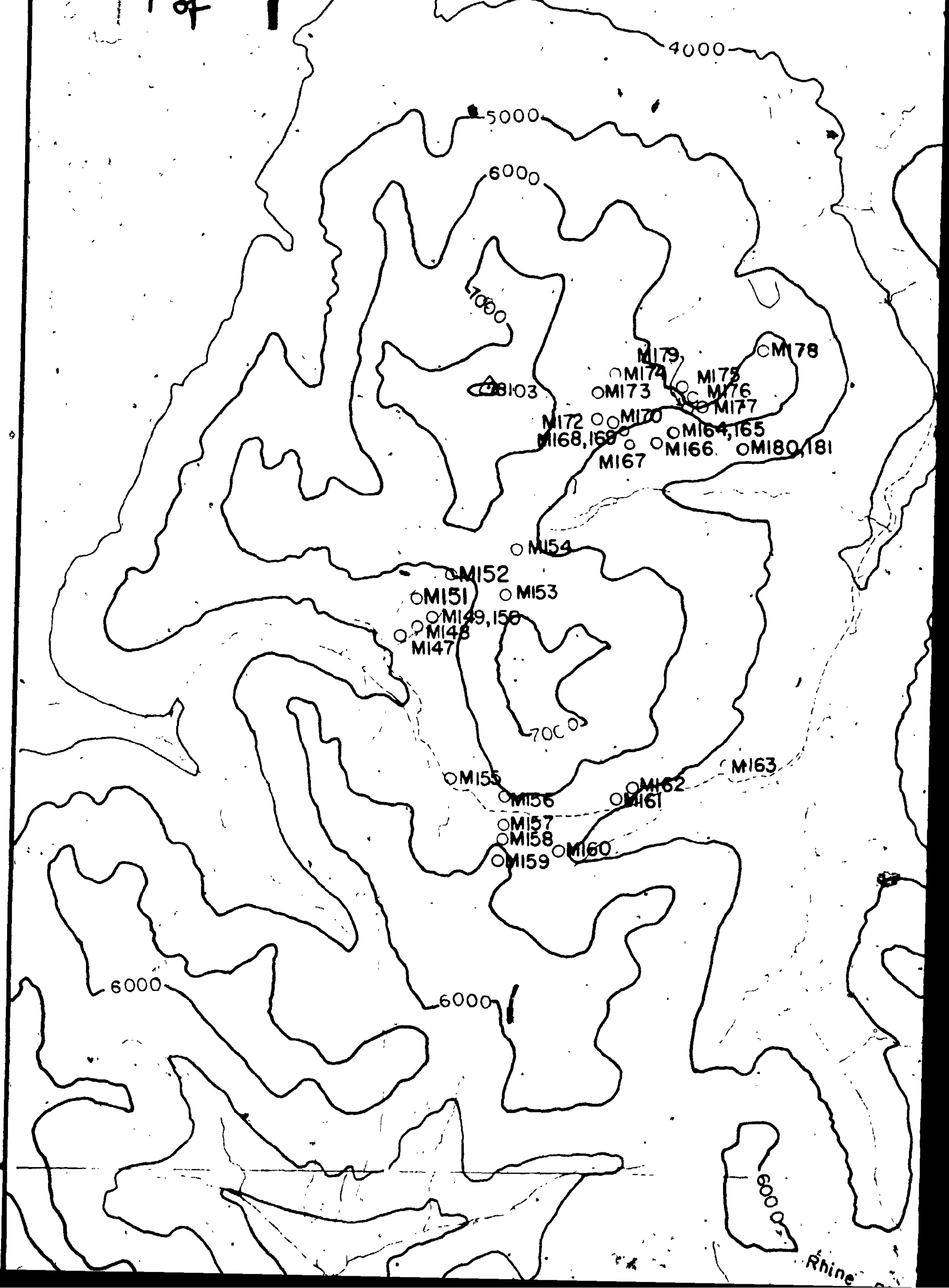
1 HAZELTON GROUP

joints inclined, vertical

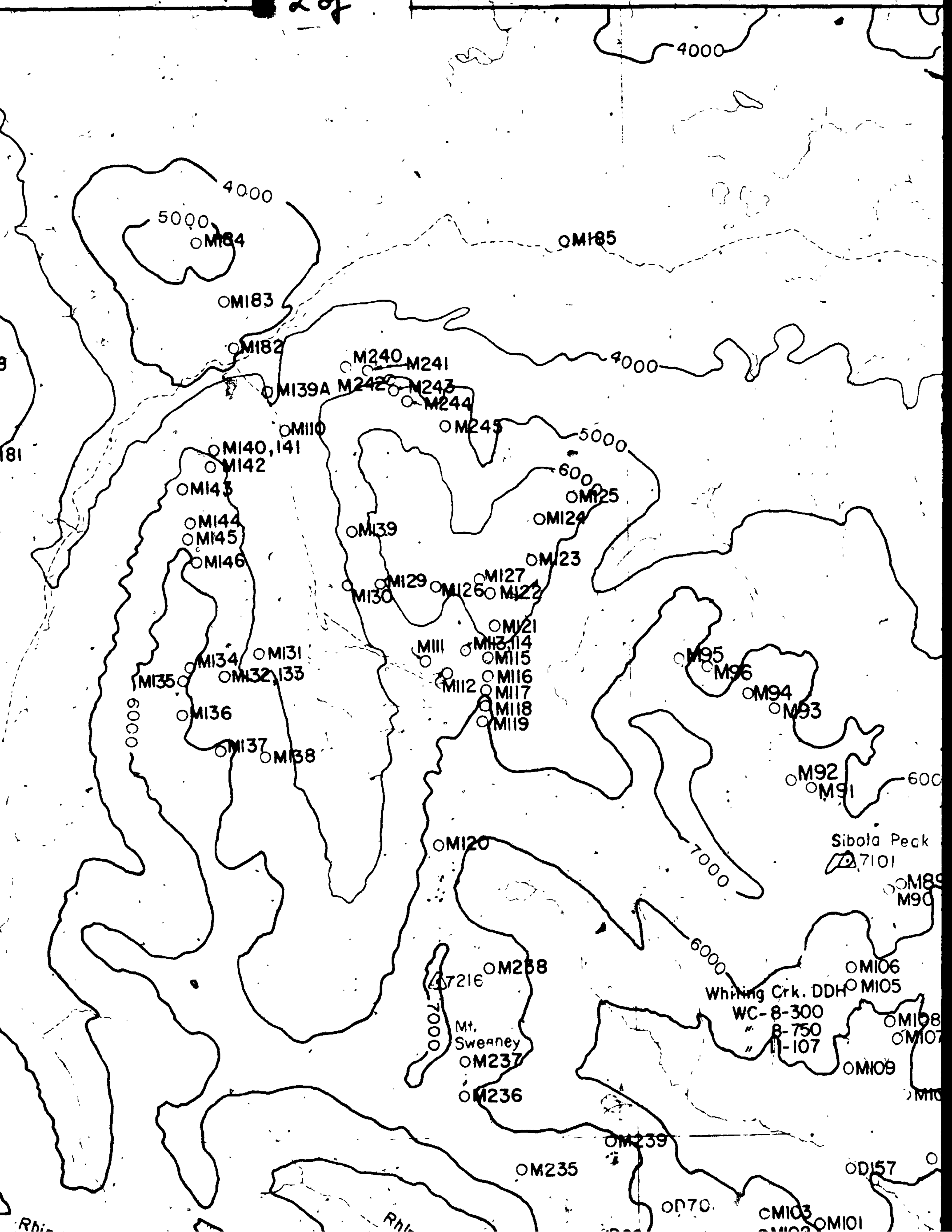
syncline anticline

major fault linear

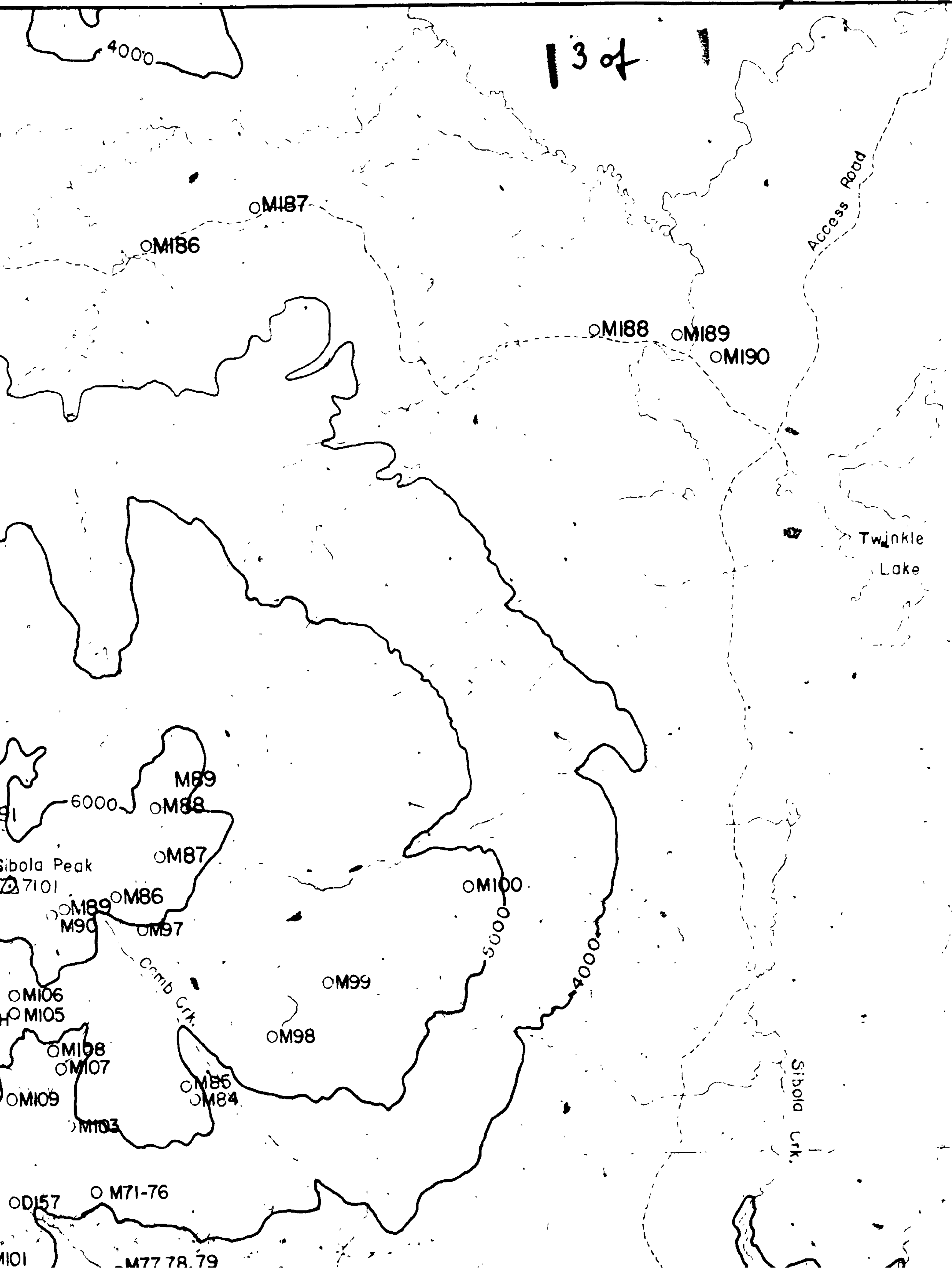
geologic contact

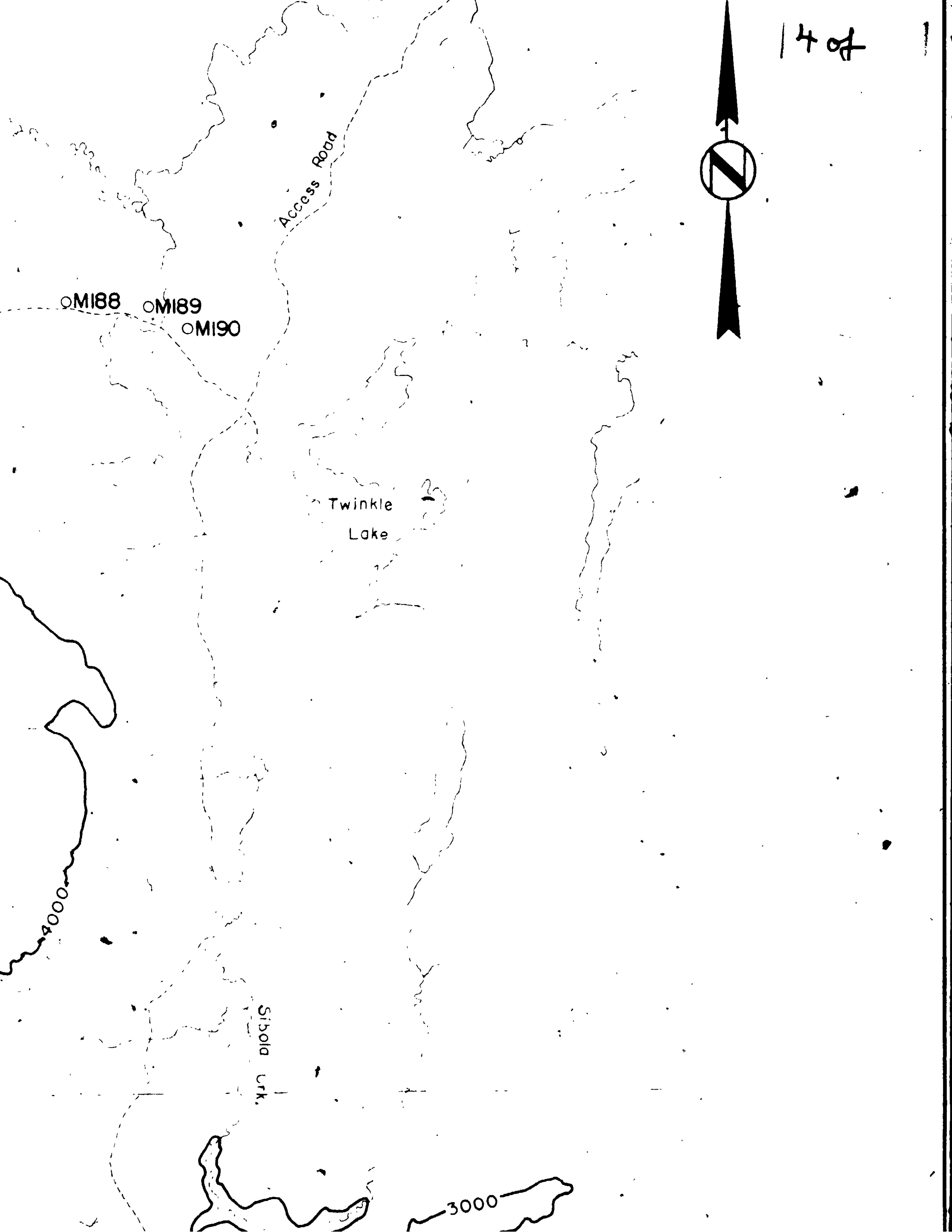


4000
5000
6000
7000
8103
M179
M178
M174
M175
M173
M176
M177
M172
M170
M168,169
M164,165
M167
M166
M180,181
M154
M152
M151
M153
M149,150
M148
M147
7000
M163
M155
M162
M156
M161
M157
M158
M160
M159
6000
6000
3°45′
6000
Rhine

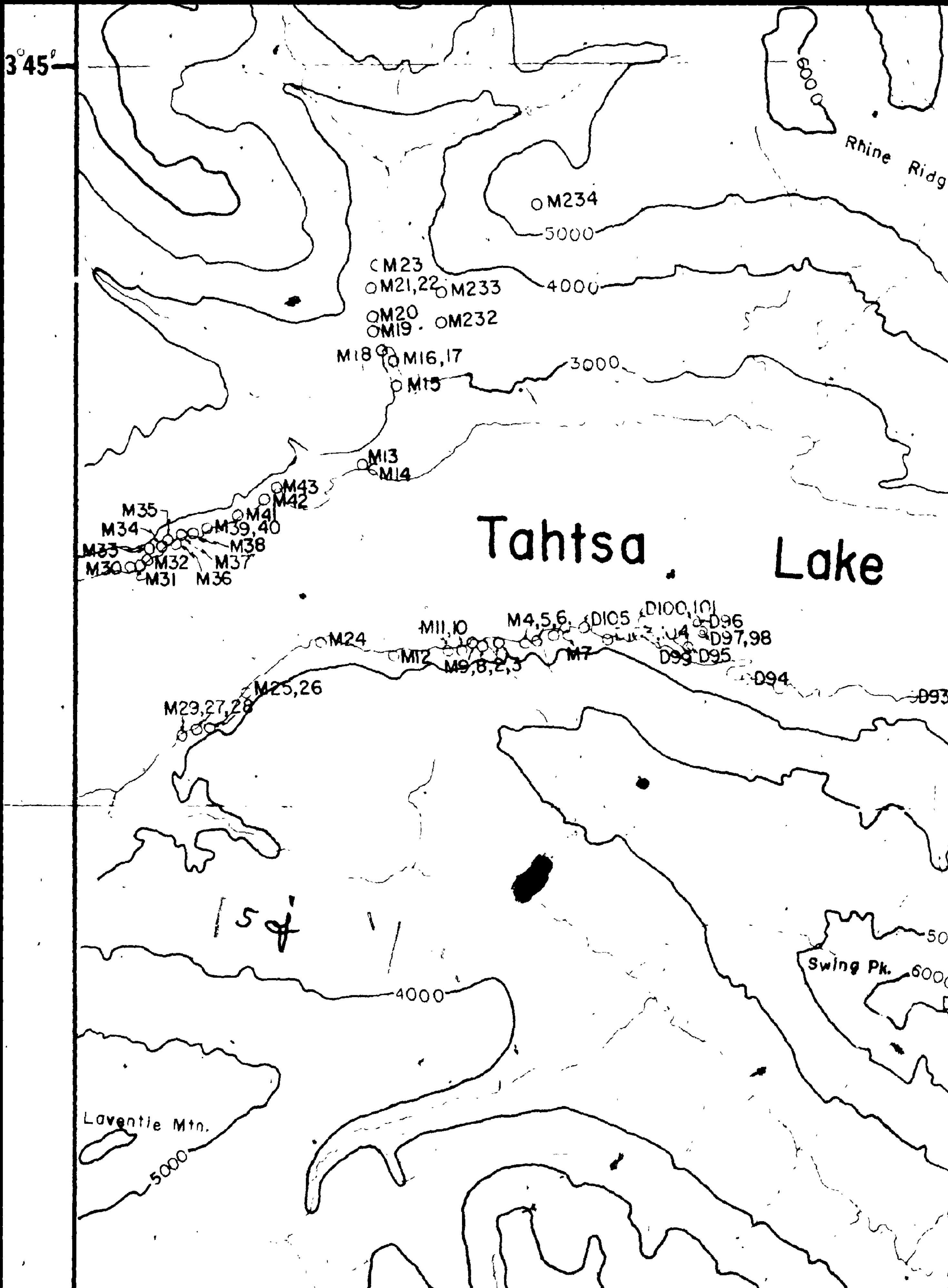


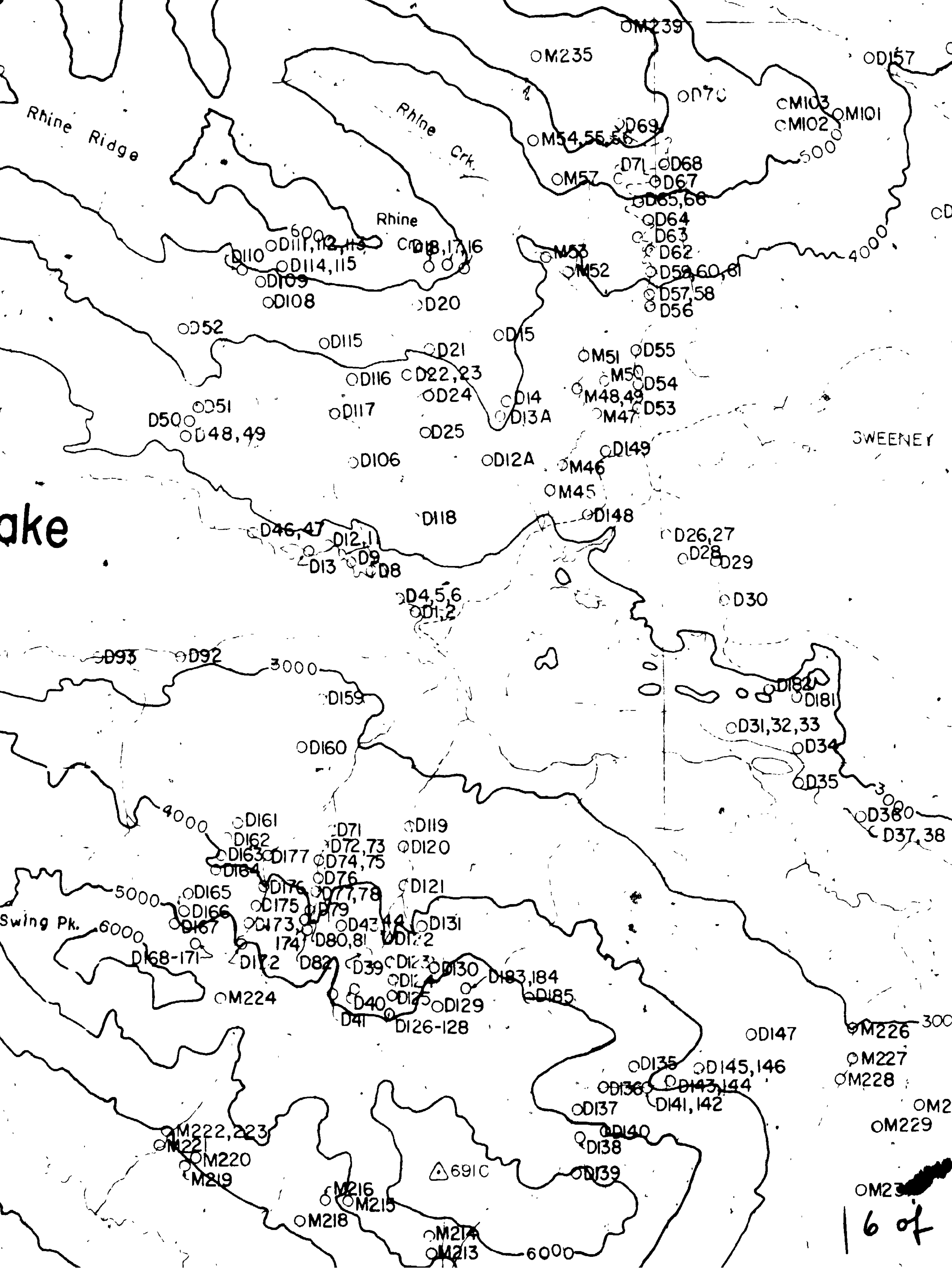
4000
5000
M184
4000
M183
M182
M185
4000
M240
M241
M242
M243
M244
M245
M139A
M110
5000
6000
M140,141
M142
M143
M125
M124
M144
M145
M146
M139
M123
M127
M129
M126
M122
M130
M121
M111
M113,114
M115
M116
M112
M117
M118
M119
M134
M131
M132,133
M135
M136
6000
M137
M138
M95
M96
M94
M93
M92
M91
600
M120
Sibola Peak
7101
7000
M89
M90
6000
M238
7216
7000
Mt. Sweeney
M237
M236
M106
M105
Whiting Crk. DDH
WC-8-300
" 8-750
" 11-107
M108
M107
M109
M239
M235
D157
D70
M103
M101
181


4000
OM187
OM186
OM188
OM189
OM190
Access Road
Twinkle
Lake
M89
6000
OM88
OM87
Sibola Peak
7101
OM89
OM86
M90
OM97
OM100
5000
4000
Comb Crk.
OM99
OM106
OM105
OM98
OM108
OM107
OM85
OM84
OM109
M103
Sibola Crk.
OD157
O M71-76
M101
M77,78,79

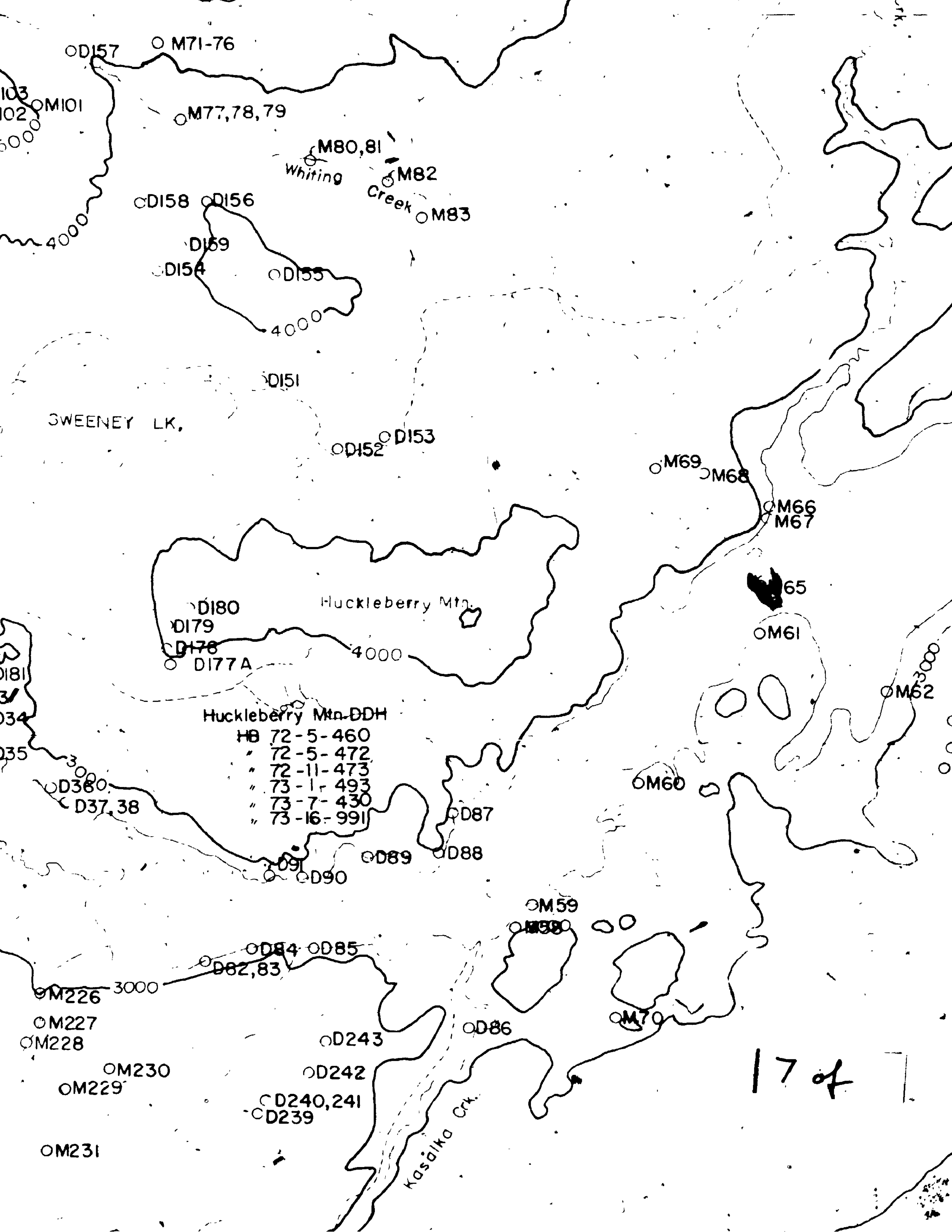


N
Access Road
M188
M189
M190
Twinkle
Lake
4000
Sibola Crk.
3000

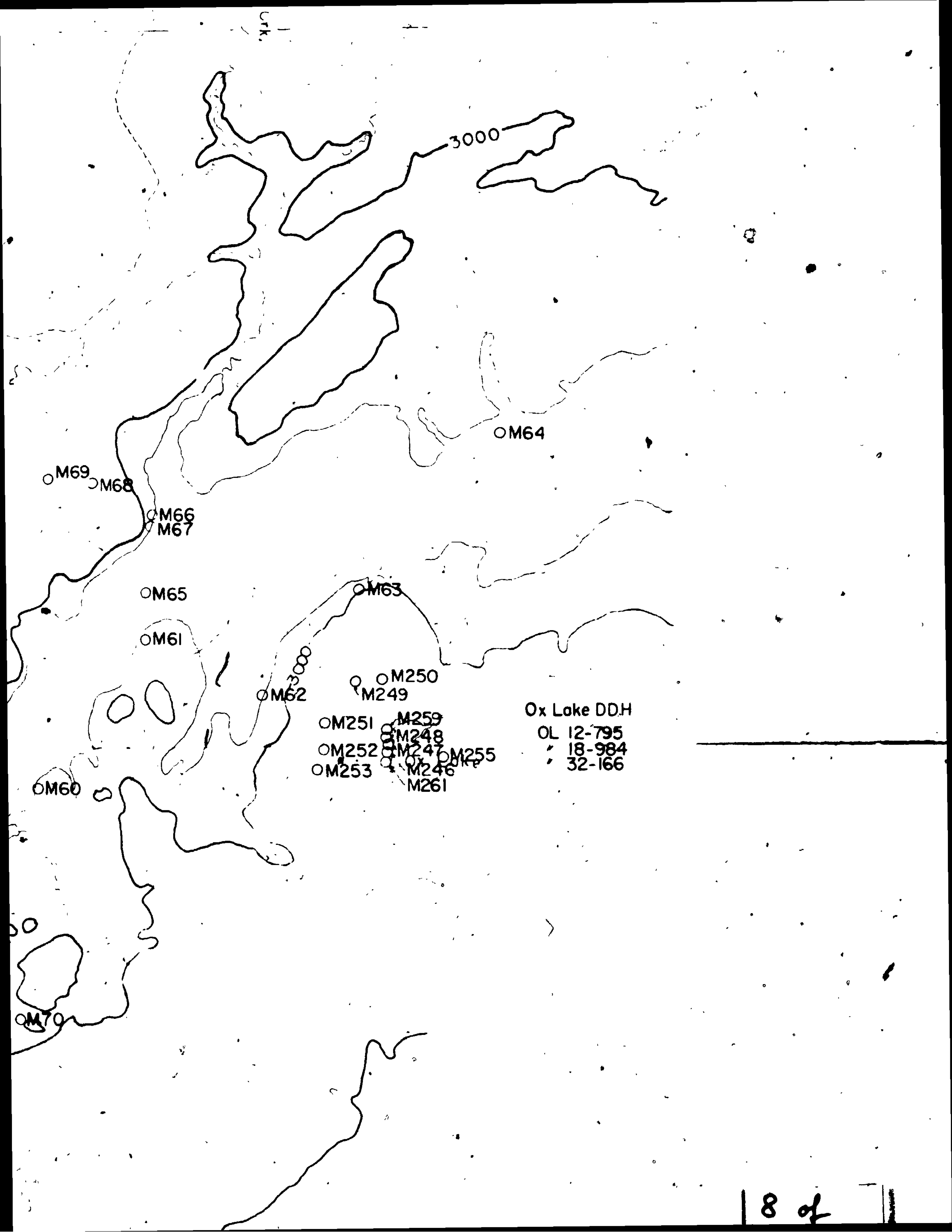

3°45'
Rhine Ridge
M234
5000
4000
3000
M23
M21,22
M233
M20
M19
M232
M18
M16,17
M15
M13
M14
M43
M42
M41
M35
M34
M39,40
M38
M33
M37
M30
M32
M31
M36
Tahtsa Lake
M11,10
M4,5,6
D105
D100,101
D96
D97,98
M24
M12
M9,8,2,3
M7
D99
D95
D94
D93
M25,26
M29,27,28
15'
Swing Pk.
6000
4000
Laventie Mtn.
5000



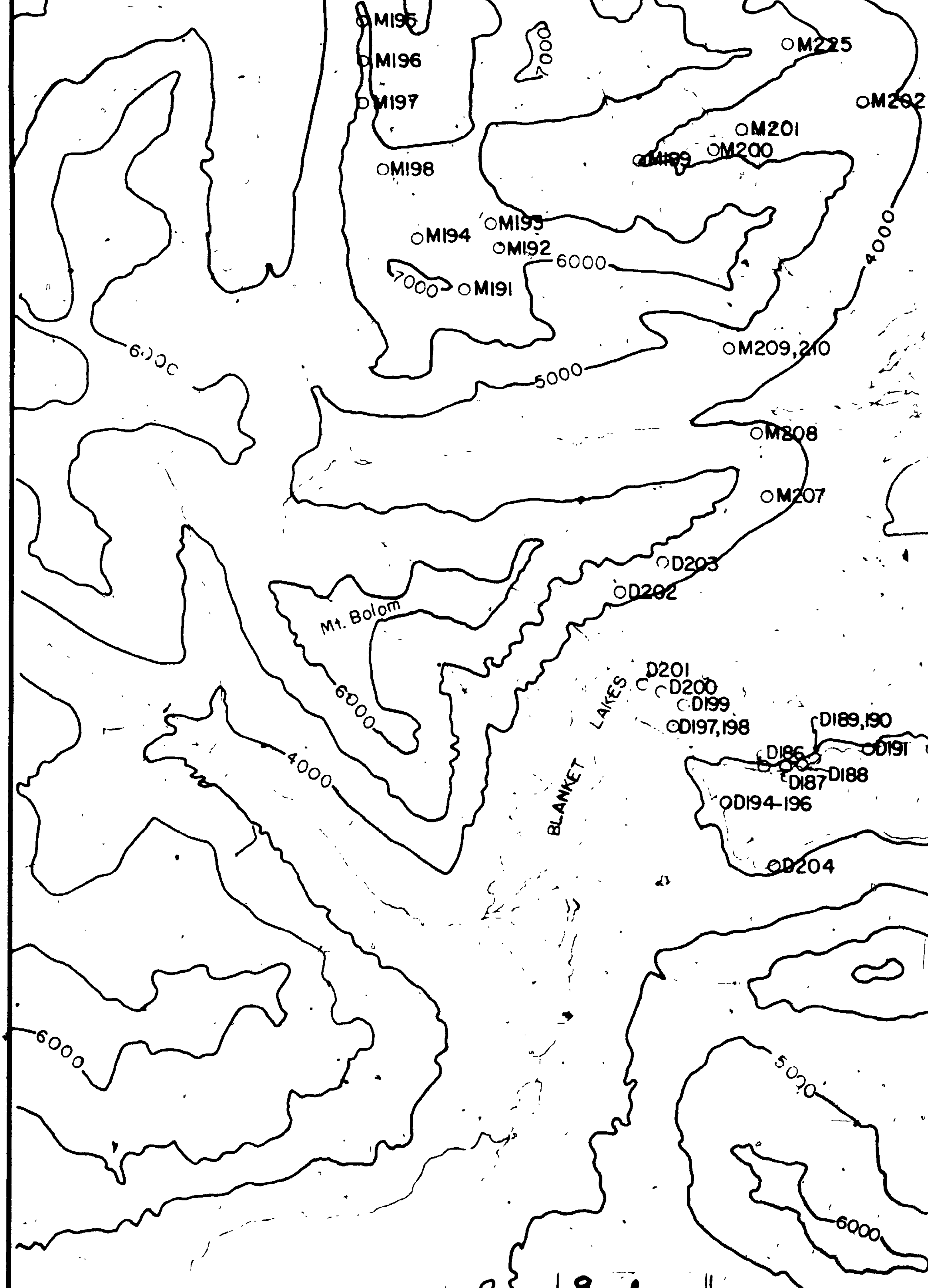
Rhine Ridge
Rhine Crk.
Rhine Crk.
ake
SWEENEY
Swing Pk.
6000
5000
4000
3000
6910
M239
M235
D157
D70
M103
M101
M102
D69
M54,55,56
D71
D68
M57
D67
D65,66
D64
D63
D62
D59,60,61
D57,58
D56
D111,112,113
D110
D114,115
D109
D108
D18,17,16
M53
M52
D20
D52
D115
D15
D21
M51
D55
D116
D22,23
M50
D54
D24
D14
M48,49
D53
D51
D50
D117
D13A
M47
D48,49
D25
D149
D106
D12A
M46
M45
D118
D148
D46,47
D12,11
D26,27
D9
D28
D29
D13
D8
D4,5,6
D1,2
D30
D93
D92
D182
D181
D159
D31,32,33
D160
D34
D35
D36
D37,38
D161
D162
D71
D119
D72,73
D163
D177
D74,75
D120
D164
D76
D165
D176
D77,78
D121
D166
D175
D79
D173
D43
D131
D167
174
D80,81
D168-171
D172
D82
D39
D130
D183,184
D185
M224
D40
D129
D41
D126-128
D147
M226
M227
D135
D145,146
M228
D136
D143,144
D141,142
D137
M229
M222,223
D140
M221
D138
M220
M219
D139
M216
M215
M218
M214
M213



D157
M71-76
M101
M77,78,79
M80,81
Whiting
Creek
M82
M83
D158
D156
4000
D159
D154
D155
D151
SWEENEY LK.
D153
D152
M69
M68
M66
M67
65
Huckleberry Mtn.
D180
D179
D178
D177A
M61
M62
3000
Huckleberry Mtn DDH
HB 72-5-460
" 72-5-472
" 72-11-473
" 73-1-493
" 73-7-430
" 73-16-991
D36
D37,38
M60
D87
D88
D89
D91
D90
M59
D84
D85
D82,83
M226
M227
M228
M230
M229
M231
D243
D242
D240,241
D239
D86
M70
Kasalka Crk.
17 of



Crk.
3000
M64
M69
M68
M66
M67
M65
M63
M61
3000
M250
M249
M62
M251
M259
M248
M252
M247
M255
M253
M246
M261
Ox Lake
Ox Lake DD.H
OL 12-795
" 18-984
" 32-166
M60
M70
8 of


M195
M196
M197
M198
7000
M225
M202
M201
M200
M199
M194
M193
M192
M191
7000
6000
4000
6000
M209,210
5000
M208
M207
D203
D202
Mt. Bolom
6000
4000
D201
D200
D199
D197,198
BLANKET
LAKES
D189,190
D191
D186
D187
D188
D194-196
D204
6000
5000
6000

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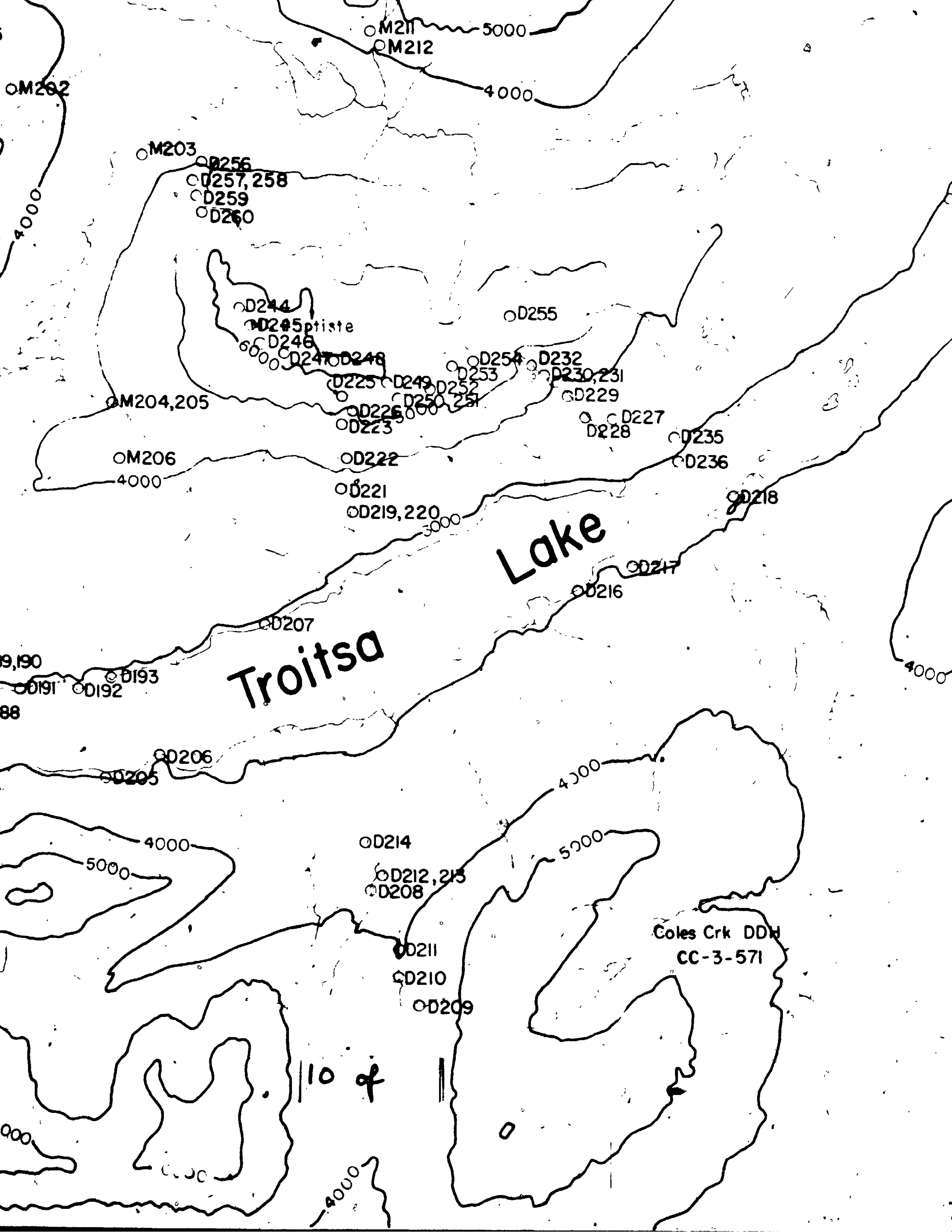

M211
M212
5000
4000
M202
M203
D256
D257,258
D259
D260
4000
D244
D245
D246
6000
D247
D248
D225
D249
D252
D250,251
D254
D253
D232
D230,231
D229
D255
M204,205
D226
5000
D223
D227
D228
D235
D236
M206
D222
4000
D221
D219,220
3000
D218
Troitsa Lake
D217
D216
D207
D193
D191
D192
D206
D205
4000
5000
D214
D212,213
D208
D211
D210
D209
4000
5000
Coles Crk DDH
CC-3-571
4000

FIG

SAMPLE

○D25 Rock sample

0

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FIGURE 25

SAMPLE LOCATIONS

○D25 Rock sample location / specimen no.